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EFFECTS OF SIMULATED ARTIFICIAL GRAVITY ON HUMAN PERFORMANCE

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16. Abstract

The ability of test subjects to perform operational type tasks was evaluated at rotational rates to 6 rpm and radii to 78 ft (24 m). The tasks included fine motor activity, mental operations, postural equilibrium, cargo handling, radial and tangential locomotion. Performance data indicate that 6 rpm presents a physiological limit at radii to 75 ft (23 m). Radial locomotion was not found to produce excessive adverse stimuli, and tangential locomotion was readily accomplished at walking rates of 2 to 4.8 ft/s (.6 to 1.4 m/s). The absence of vision dramatically reduced an individual's postural equilibrium during rotation. The use of selected anti-motion pharmaceuticals had, generally, a positive effect upon psychomotor performance at 6 rpm, but did not prove to be a panacea for the adverse effects of rotation at this rate.

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FOREWORD

The study reported herein was designed to provide insight into the problems related to human residence in a space vehicle subjected to rotation in order to provide an artificial gravity environment. The program design was an extension to the evaluation of human performance obtained during the conduct of Contract NAS1-9711.

The data are reported in U.S. customary and SI units. Inasmuch as the work was measured and analysed with the U.S. customary units, these are presented first. This practice makes both the presentation, as well as the comprehension of the data by the reader more effective. The gratitude of the authors is extended to Dr. Ashton Graybiel of the U.S. Naval Aerospace Medical Institute, who provided the coded anti-motion sickness pharmaceuticals and expert advice during the course of test subject selection. The dedication and professionalism of the test team is gratefully acknowledged.

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ABBREVIATIONS AND SYMBOLS

The data presented in this document are presented in English units followed by the Sl units in parenthesis. The following abbreviations and symbols have been used:

AM	Morning
Anti-spin	Facing opposite the direction of rotation
bpm	Beats per minute
C	Condition
cf	Compare
cm	Centimeters
CM	Complex mode (LCC)
CMACL	Composite mood adjective checklist
D	Direction test subject faces
DRT	Decision response time device
EC	Eyes closed (ataxia)
e.g.	For example
EKG	Electrocardiogram
EO	Eyes open (ataxia)
ft	Feet
ft/s	Feet per second
g	Gravity
HM	Head Motions

HC	Head motions with eyes closed
HO	Head motions with eyes open
HX	No head motions (warmup trial)
hr	Hour
i.e.	That is
in.	Inches
kg	Kilogram
lb	Pounds
LCC	Langley complex coordination device
M	Mean
m	Meters
min	Minute
mm Hg	Millimeters of mercury
m/s	Meters per second
MSP	Multi-station protocol
N	Number of test measures
NS	Not significant
NR/SD	North American Rockwell's Space Division
P	Protocol or periods
PM	Afternoon
Pro-Spin	Facing the direction of rotation
Rad	Radial
rad/s	Radians per second

R and L	Right and left (ataxia)
rpm	Revolutions per minute
RTF	Rotational Test Facility
s	Second
S	Test subject (or subjects)
SD	Standard deviation
SH	STD LCC W/head movements
SOL	Stand on leg (ataxia)
SSP	Single station protocol
STD	Standard mode (LCC)
SR	Sharpened Rhomberg (ataxia)
T	Test
V	Rotational rate
vs	In comparison to or with
W/	With
WOF	Walk on floor (ataxia)
yrs	Years
=	Equal to
≥	Equal to or greater than
≤	Equal to or less than
-	Negative
+	Positive

EFFECTS OF SIMULATED ARTIFICIAL GRAVITY ON HUMAN PERFORMANCE

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SUMMARY

Human performance in the rotating environment, with respect to the impact of the various forces and attendant psychophysiological stimuli on man's ability to perform operational type tasks, was evaluated as it might affect the design and operation of future space vehicles providing an artificial gravity environment. The evaluations were conducted at angular rates to 6 rpm and radii to 80 feet (24 m). The experimental study included psychomotor testing, postural equilibrium evaluations, and short term memory measurements, all with and without the use of antimotion sickness pharmaceuticals; as well as active and passive locomotion. The latter studies including riding an elevator at radial rates to 8 ft/s (2.4 m/s); self paced radial transfer on a ladder system, and tangential walking, with cargo handling, while suspended in a sling system.

An adjective checklist of mood factors revealed definite mood change in response to the rotational stimuli, with the pharmaceuticals modifying these feelings significantly during the course of a rotational test period. The results with the pharmaceuticals relative to the psychomotor evaluations were mixed, generally indicating a positive effect, but not providing complete protection from malaise.

Postural equilibrium was negatively affected by rotation. It was found that the absence of vision, during rotation, resulted in an almost absolute loss of body control. These factors may have significant importance to emergency operations in space activities. Patterned head movements hastened the return of postural equilibrium following rotation.

The psychomotor test devices revealed many significant interactions with respect to rotational rates, number of trials at a sitting, and associated head movements. The performance at 6 rpm was most frequently the slowest.

Ladders with graduated rung spacing were perferred to those with constant rung spacing, due to the advantages obtained in moving through the gravity gradients. Climbing rates averaged approximately 2.4 ft/s (.73 m/s), while tangential locomotion rates were found to be approximately 3.0 ft/s (.91 m/s), with some performances to 5 ft/s (1.5 m/s). Cargo transfer and

handling presented no problems at radii beyond 40 ft (12 m). Some traction and body control problems, encountered at less than 0.1 g, were only slightly improved by the curved floor configuration. There was no advantage of the curved over the flat floor configuration at the 50 ft (15 m) radius. The rate of 6 rpm appears to provide a critical limit for physiological tolerance to rotation at radii of 75 ft (23 m).

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INTRODUCTION

Research efforts have been in progress for the past few years to define the overall requirements for mission planning and vehicle design for post-Apollo space programs. One of the major efforts has been concerned with the station/base vehicle category. These vehicles will provide adequate space laboratories, wherein research programs may be conducted which take advantage of the lack of external atmosphere, subgravity, weightlessness, availability of high vacuum, and extreme isolation. Investigations have been designed to pursue the fundamental principals of astronomy, chemistry, physics, physiology, medicine, as well as biotechnology, earth resources, and advanced spacecraft technology. Some of the principal objectives will include advancement in basic knowledge, improved health service techniques, new analytical and manufacturing techniques, communications services, earth resources utilization, international cooperation, and national security. The coming period of space operations for the near future have been described as "the translation from sorties into space to the occupation of space" (Reference 1). The timely conduct of fundamental, ground-based engineering evaluations relative to vehicular configuration, life support provisions, and man-machine interfaces are required to establish design parameters and operational procedures to insure mission success, as well as to extend man's capabilities to live and produce useful work in space.

The results of space flights of Apollo astronauts up to 14 days in the American space programs have not indicated a requirement for an artificial g environment (Reference 2). It is anticipated that the Skylab missions will better define the impact of weightlessness on the cardiovascular system and the potential requirement for prophylactic therapeutic regimens to insure crew health upon return to earth, following extended exposure to weightlessness (Reference 3). Based upon the results that have been obtained postflight relative to orthostatic tolerance, the provison of an artificial g environment has been suggested as the ideal prophylactic measure to prevent or alleviate the loss of electrolytes, shift in body water, and potentially to modify the degree of cardiovascular deconditioning which has been observed in space flights to date (Reference 4). Many scientists in the USSR are quite positive with respect to the requirement for artificial g for long duration flights, based on total experience, and with particular reference to the experience gained in the 18-day flight of Soyuz 9 in June of 1970 (References 5, 6).

At the present time, the real justification for the artificial g environment has been predicated on the enhancement of crew comfort, convenience, and efficiency (Reference 7). The prospective use of scientists and engineers who lack extensive flight experience to conduct experimental work, makes it desirable to consider the provision of a more earthlike environment for them. It has been suggested that many operational procedures and crew activities may be accomplished more easily through habit or reflex in the artificial g environment, whereas, extensive training with new techniques, and equipment modifications will be required to accomplish useful work in the weightless environment. However, the artificial g environment is proposed for the living area only, since many, if not most, of the research activities will be performed in the weightless environment, to evaluate the interaction of the experimental parameters with the phenomenological absence of g.

The NASA Langley Research Center and selected research laboratories have been cooperatively investigating the impact of the rotating environment on human performance. None of the studies has been designed to answer the question of which is more desirable, artificial or zero g. The answer to this question can only be obtained, with any degree of certainty, from manned space flights of progressively longer duration. However, the potential requirement for artificial g to enhance crew performance and/or mission successs on future space ventures makes it crucial to evaluate the impact of the rotating environment on crew operational performance, especially with respect to the potential impact on vehicle design, configuration, and crew selection criteria. These areas of concern may require modification due to the effects of the attendant Coriolis forces, cross-coupled angular accelerations, g gradients, and the associated physiological stimuli derived from the rotational environment. It is essential that valid data relative to the magnitude of the impact of these factors on overall crew requirements be available to the human factors and design engineers when vehicle development and mission planning become eminent.

It is recognized that the fidelity of ground-based simulations suffer from the impact of the normal earth g and the induced force vector in the rotating environment. Nevertheless, the main factor pursued in these evaluations are intimately associated with proprioceptive-visual-vestibular responses to the various forces. Therefore, the simulation may be considered a worst case situation, and corrective procedures and/or design criteria established by these studies should be equally effective in the less complex environment of the rotating space vehicle. This is especially true with respect to the Coriolis forces and cross-coupled angular accelerations which will be identical in magnitude, though different in orientation with respect to the semicircular canals.

The general objective of the work discussed herein was to obtain research data relative to the performance capabilities or degradations of individuals performing both gross and fine psychomotor tasks in the rotational environment. These evaluations were designed to complement and expand the data obtained previously on Contract NAS1-9711 (Reference 8). The results are intended to provide numerical and subjective data, which may be used as design criteria and crew operational procedures, for space vehicles providing an artificial environment. The rational for the experimental design was predicated on the literature pertaining to design and crew operational limitations derived from both experimental and intuitive considerations of the rotational environment (References 9, 10).

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I. FACILITIES AND EQUIPMENT

The tests and evaluations discussed herein were performed at the North American Rockwell's Space Division, in Downey, California. The simulated artificial tests were conducted on the rotational test facility comprised of a block house control center and a hydraulically driven 160-ft (48.8 m) long rotating beam (Figure 1). The rotating beam is 80 inches (2 m) wide, protected along its length by seven ft (2 m) high walls on each side. A crew module is located at a mean radius of 75 ft (23 m), has internal dimensions of 10 ft (3 m) width by 40 ft (12 m) length. The module is separated into functional areas containing four bunks, toilet, shower, lavatory, kitchen-recreation area, and a test area (Figure 2). The module cants to provide a walking surface normal to the induced g vector by means of a pendulum actuated hydraulic pump system. The module is equipped with a quick-opening hatch and self-adjusting stairway, to permit ingress and egress while the beam is in motion. Adequate sewage and potable water storage capacity is available to permit continuous testing with a crew of four men for 30 days without resupply. A 60 inch (1.5 m) hollow central bearing permits ingress and egress onto the RTF while it is rotating.

An emergency medical facility has been installed at one side of the control center, which provides an area for dressing and instrumenting the test subjects, as well as dispensing pharmaceuticals. Psychomotor test devices utilized in the crew module included two Langley complex coordinators which were oriented so that the test subjects were facing radially, toward the hub (Figure 3). This device is comprised of four sets of paired lights. Test lights are triggered by a pre-programmed drum. They are matched by the test subject utilizing two variable hand switches and two variable pedals. A second device contained a complex mix mode drum, which provided the test subject with a key which required that the hand/foot controlled lights be either matched or offset by one or two positions in order to complete a light set and receive the next set of lights and code. Time for the successful matching of 50 sets of light patterns was the measure of performance, which was recorded automatically in the control center. Also, a Stromberg dexterity device, which requires the patterned transfer of 54 colored blocks through a distance of approximately 20 inches (0.5 m) was used to evaluate the effect of moderate arm and head motions (Figure 4). This test was performed while facing pro-spin, anti-spin, and radially, with time used as a measure of performance and recorded by an assistant. Mental responses to the environment were evaluated, utilizing three versions of the California Reading Test, which measures reading, vocabulary, and comprehension, during measured time periods. Memory span was evaluated by requiring the test subjects to

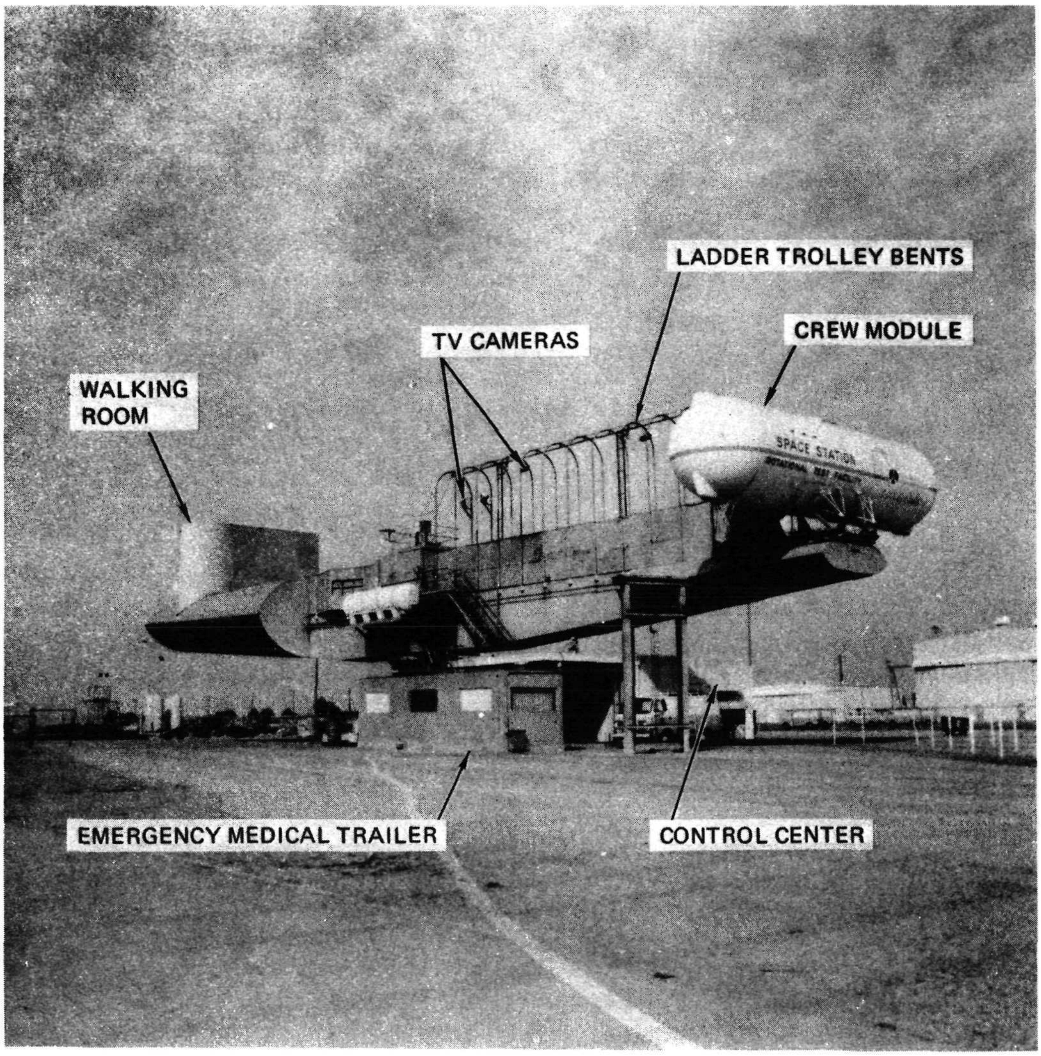

Figure 1. Rotational Test Facility

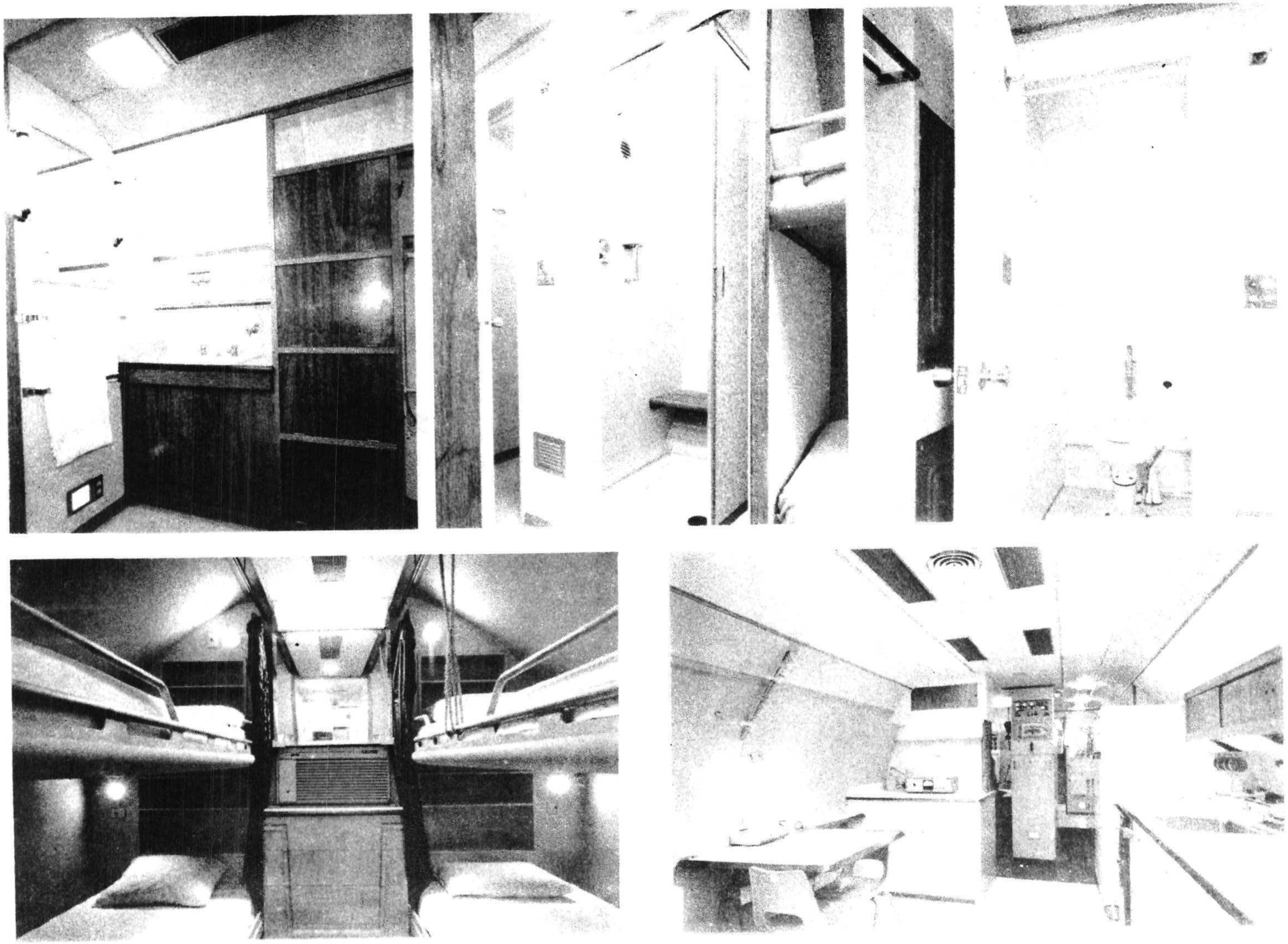

Figure 2. Crew Module Interior

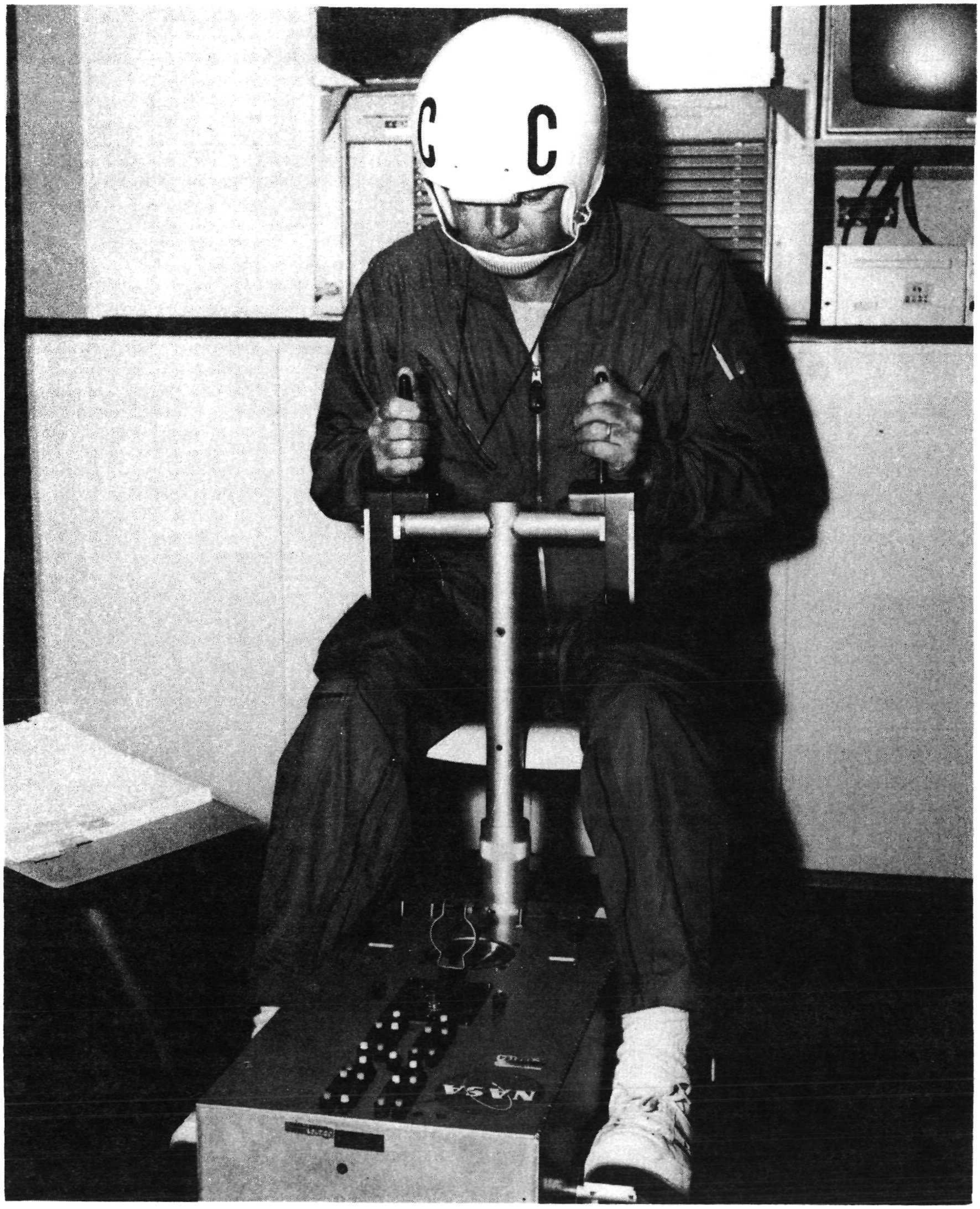

Figure 3. Langley Complex Coordination Device

Figure 4. Stromberg Dexterity Device

recall increasing numerical digit spans, presented in a timed sequence by means of a tape recorder.

Work stations, located at radii of 40 and 80 feet (12 and 24 m), house adjustable couches, oriented horizontally to align the long axis of the test subject with the artificial g vector (Figure 5). The lateral orientation of the couch may be adjusted by the test subject, from a position facing in the anti-spin direction in 45 degree increments, to a position facing in the direction of rotation (pro-spin). The 90 degree, or that position facing "up," has been designated the axial position. The couch is instrumented so that the orientation and rate of change may be recorded in the control room. The test subject's helmet is held by a "head clamp," which is also instrumented to record rotary head movements between 80 degrees left and 80 degrees right (160° arc). These stations are equipped with modified Langley Decision Response Time Devices (DRT), * which present the test subject with two light displays, located approximately 75 degrees to either side of neutral. A series of 25 lights must be sequentially deactivated by four finger switches located on a pistol grip, in response to a sequence code, which is presented to the test subject upon demand.

The data from the LCC and DRT stations were multiplexed and recorded on magnetic tape for computer reduction. As a backup measure, the data were also collected on Sanborn 568 eight-channel recorders for cross-correlation.

An overhead trolley system, located 20 feet above the beam, supports a sling system used in conjunction with the ladders, which extend from radii of approximately 5 to 60 ft (1.5 to 18 m) (Figure 6). A cart (elevator) is located between the ladders, with the rate of translation adjustable up to 8 ft/s (2.4 m/s) (Figure 7). A walkway, located on the outer edge of the beam, permits radial transfer along the total length of the rotating beam.

A series of ladder configurations was used sequentially during the test program. Ladders with constant 12-inch (30.5 cm) rung spacings (L1) were utilized in both the pro- and anti-spin orientations for the first 12 test days. These ladders were replaced with two ladders having varied rung spacings for the remaining tests. A ladder having rung spacings of 12 to 20 inches (30.5 to 50.8 cm) was installed in the pro-spin orientation (L2), and one with 9 to 18 inches (22.9 to 45.7 cm) (L3) was installed in the anti-spin orientation for the test days 13 to 23. The positional orientation of the two ladders was reversed for the concluding ten days of the test.

*The DRT was invented and developed by R.M. Chambers, R.K. Kinnerman, and J.L. McConnel of NASA/LRC. Patent has been applied for.

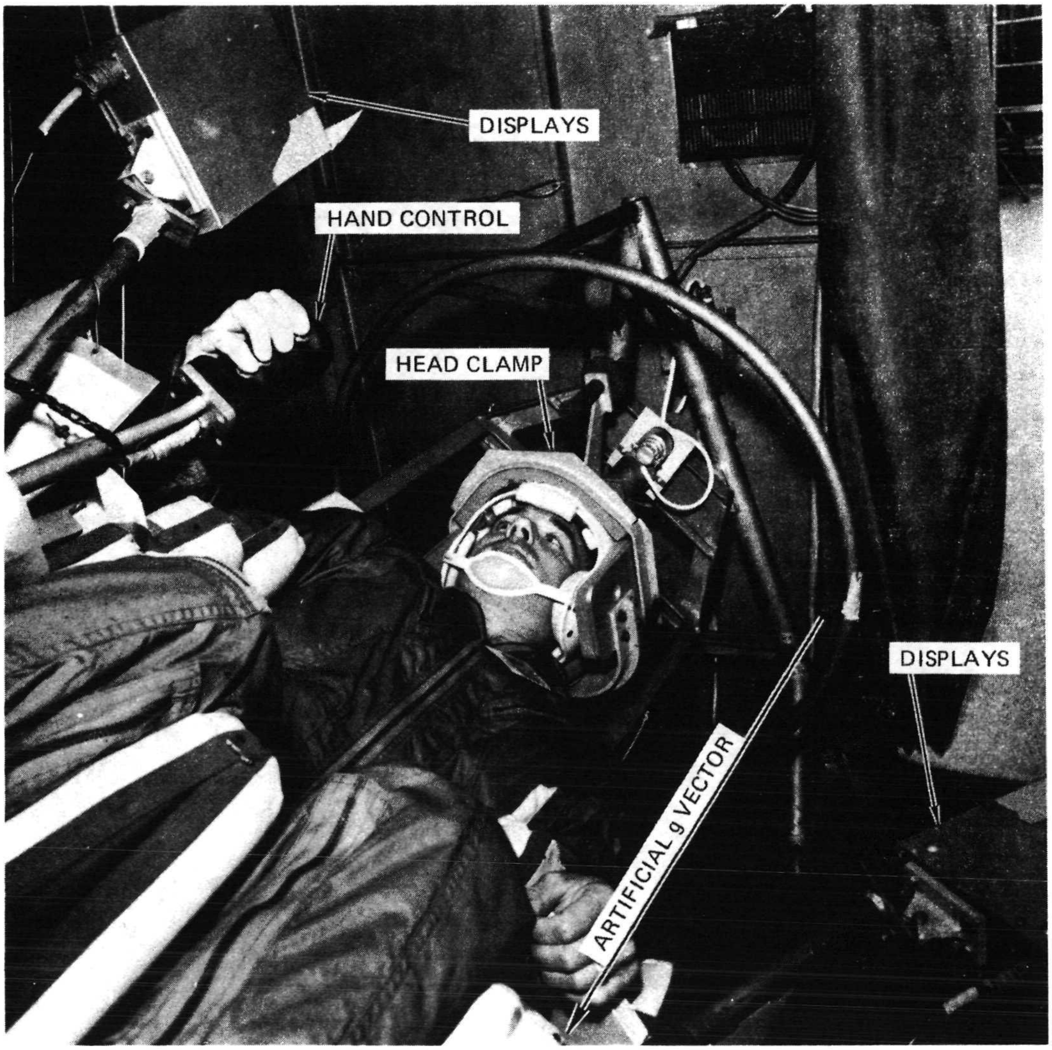

Figure 5. Typical Work Station With Decision Response Time Device

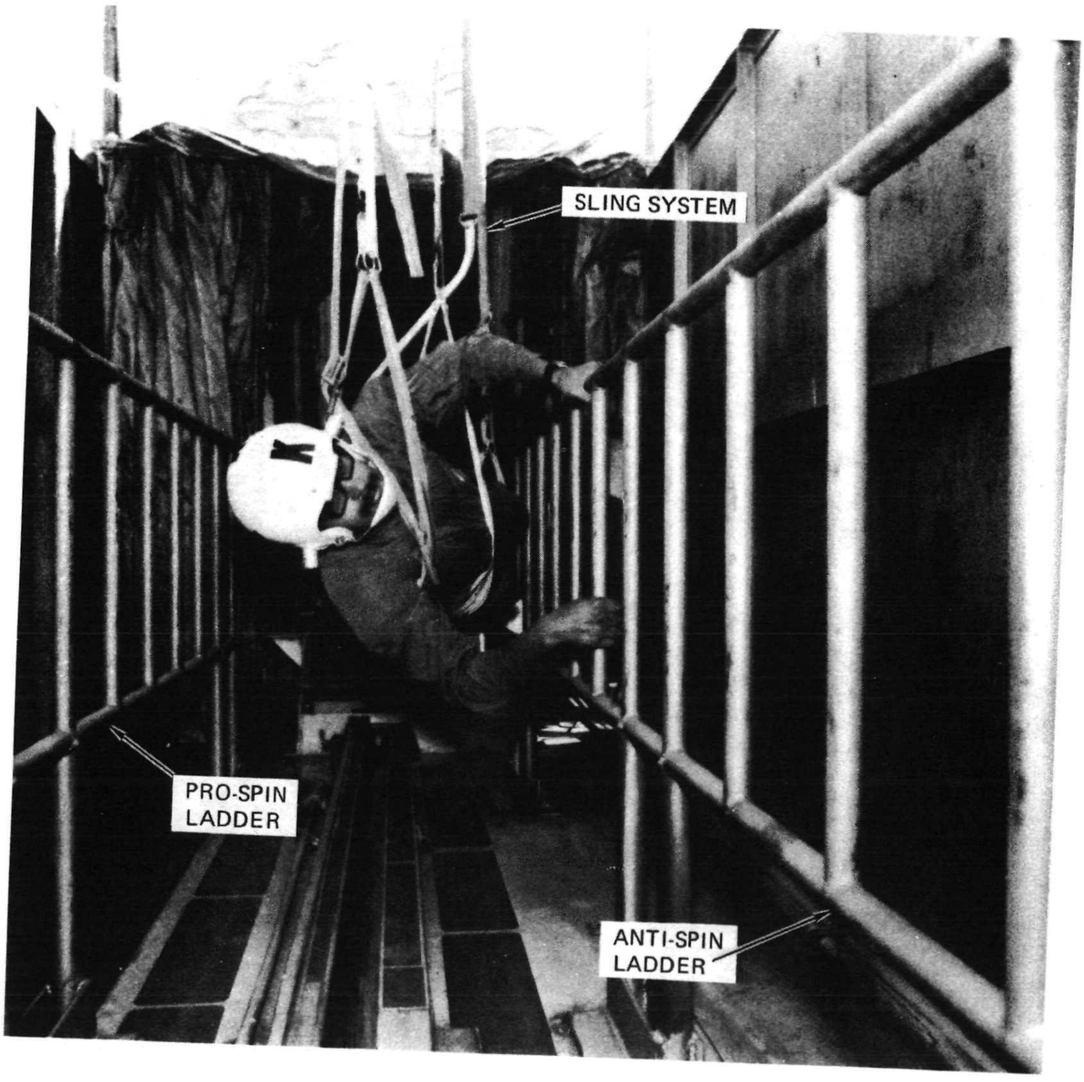

Figure 6. Ladder Climbing Evaluation

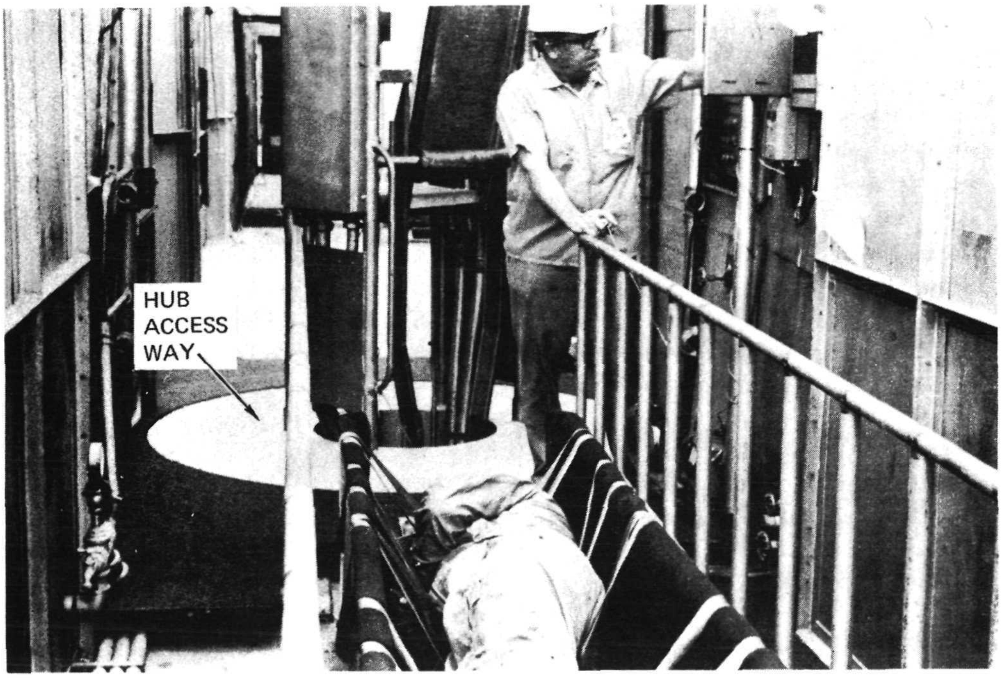

Figure 7. Elevator Cart Evaluation

A moveable enclosure, called the walking room, is cantilevered from the trailing edge of the beam. This room may be positioned at 27.5 ft (8 m), 50 ft (15 m), and 70 ft (21 m) radii. The short radius is hereafter referred to as the 30-ft (9 m) position. A trolley-sling system is installed in the top of the room, 20 ft (6 m) above the surface of the beam to align the test subject with the artificial G vector. The vertical walking surface is 20 ft (6 m) long and provided with carpet grids, to facilitate locomotion analyses (Figure 8). Either flat or curved "floors" may be utilized at the short radii, while only flat floors are provided at the 70-ft (21 m) position. The floors are symmetrical about the radial axis.

Two cargo packages, weighing 32 lb (14.5 kg) and 96 lb (43.5 kg), may be suspended independently, and transported across the room in either direction (Figure 9). Cargo bins containing eight chambers are located at either end of the room (Figure 10). Each chamber is approximately one ft^3 (0.3 m^3), and contains various sizes and weights of cargo packages, designed to simulate modular flight hardware. The modules were equipped with various handle configurations, with each handle being either external or recessed within the package as described in Table 1. The packages are transferred from four filled chambers to the four empty chambers, with time and subjective ease of handling utilized as a measure of performance.

The conduct of postural equilibrium (ataxia) was conducted on the beam of the RTF, near the hub, as depicted in Figure 11. All activities conducted during rotation of the facility were monitored in the central control room by means of closed circuit TV. Also, constant voice communication was insured through three different modes, including two separate hard-wire talk-a-phone systems and a citizen's band radio system. Each test subject was fitted with telemetric electrocardiograph transmitter, whose signals were visualized constantly on a Sanborn Model 768 visoscope and recorded periodically on a Sanborn Model 568 recorder. Selected crew activities were recorded on 16 mm color film, utilizing both remote control and hand-held cameras, for subsequent analysis and documentation.

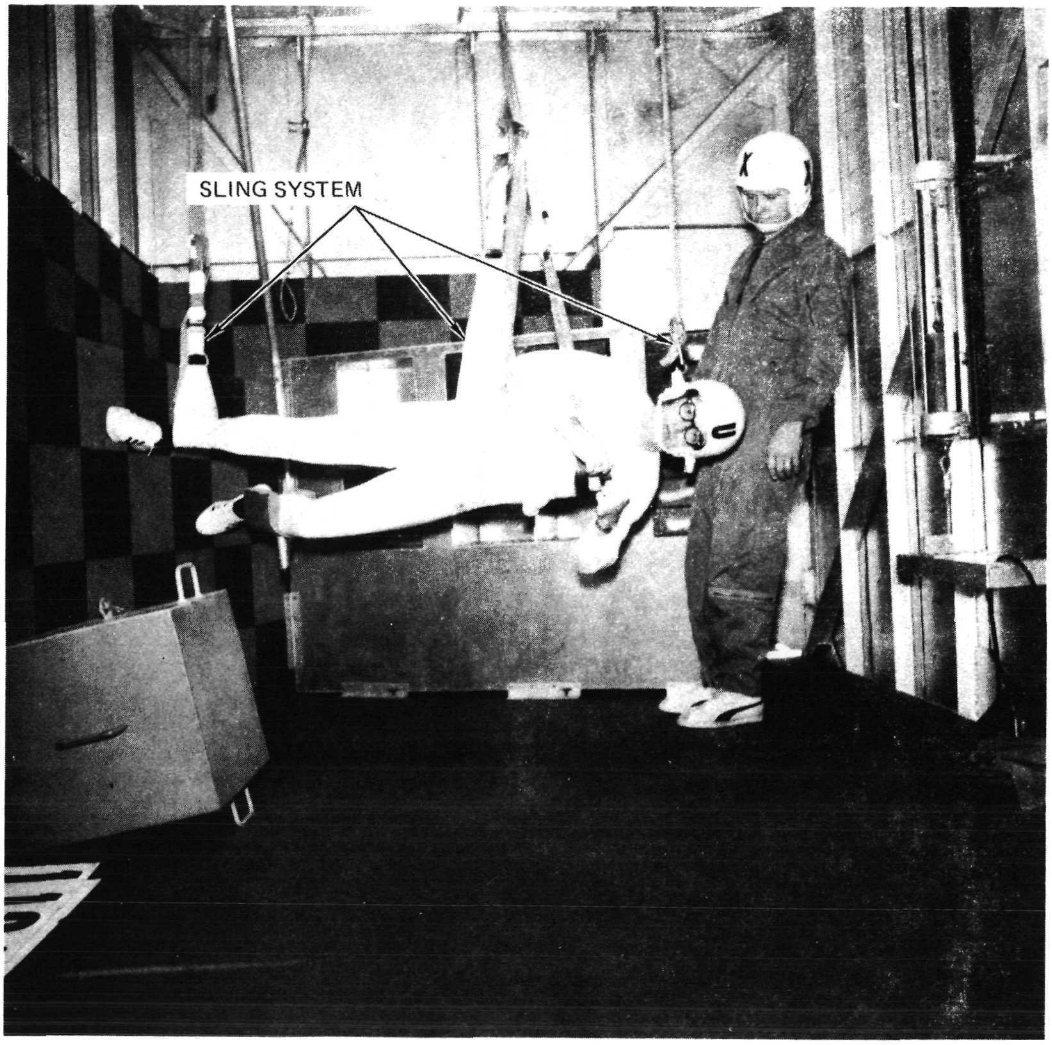

Figure 8. Walking Room Evaluation

C

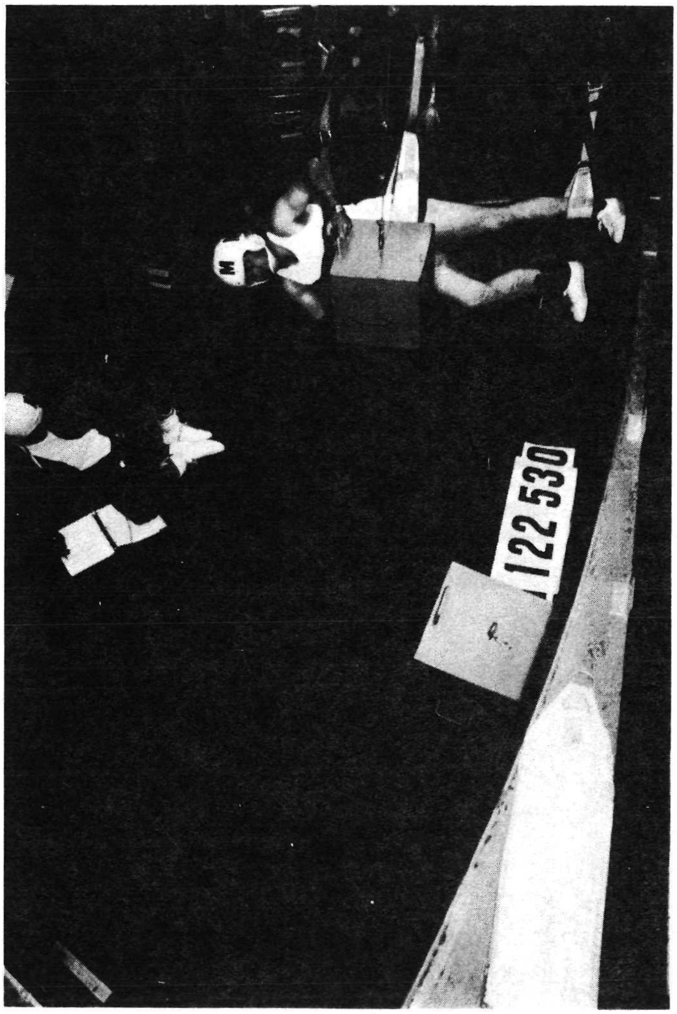

Figure 9. Cargo Transport

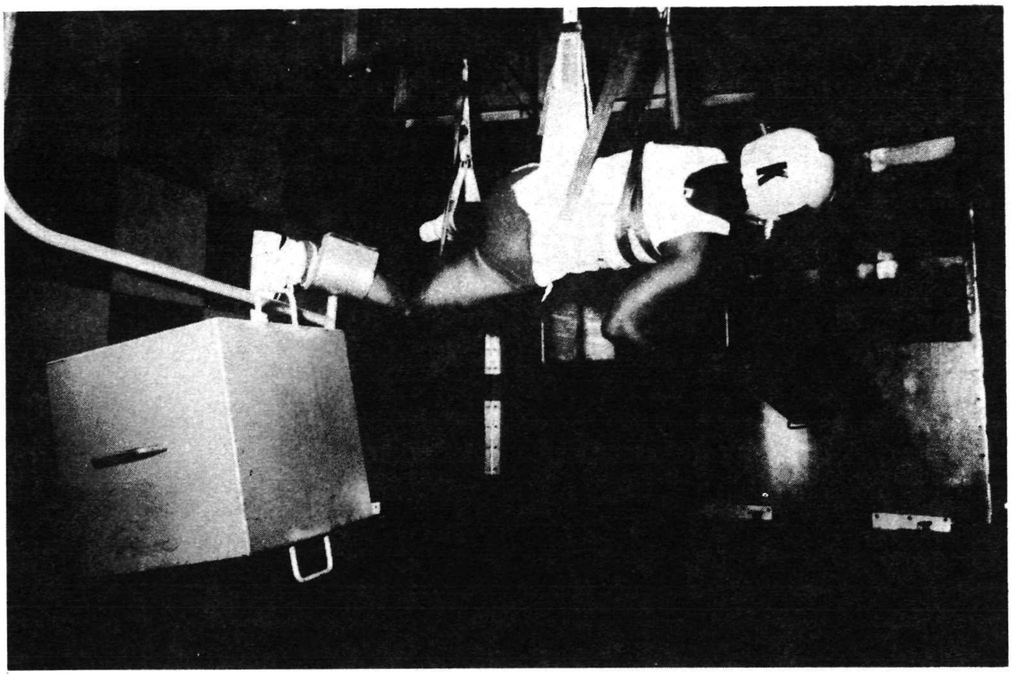

Figure 10. Cargo Handling

Figure 11. Postural Equilibrium Evaluation

Table 1. Cargo Package Descriptions

Quantity	Size in. (cm)	Mass lb (kg)	Handle Configuration
Unsupported (Handling)			
1	12^3 (30^3)	10 (4.5)	1 and 2 recessed
1	12^3 (30^3)	20 (9.1)	1 and 2 recessed
4	6 x 6 x 12 (15 x 15 x 30)	5 (2.3)	1 and 2 external
4	6 x 6 x 12	10 (4.5)	1 and 2 external
3	4 x 12 x 12 (10 x 30 x 30)	7.5 (3.4)	1 and 2 external 1 recessed
3	4 x 12 x 12 (10 x 30 x 30)	15 (6.8)	1 and 2 external 1 recessed
Supported (Transport)			
1	15^3 (38^3)	32 (14.5)	2 external
1	18^3 (46^3)	96 (43.5)	2 external

II. TESTS AND RESULTS

TEST PROTOCOL

The test program presented herein was comprised of 35 days of rotation, including two indoctrination periods. A total of 67 test sessions was conducted. A particular session was used for either psychomotor or gross motor (locomotion) activities by a test subject group. The psychomotor sessions were further divided into either single station protocol (SSP), wherein the test subject went to one station and remained for the entire session; or multiple station protocol (MSP), wherein the individual moved sequentially to one of four different test stations at approximately 20 minute intervals. The two protocols were designed to elucidate the effects of fatigue as well as the impact of the stimuli produced during radial locomotion on performance. The scheduling of the various sessions was randomized to reduce the influence of morning and afternoon differences on test subject performance data. The sequence of tests within a session was also randomized during both psychomotor and locomotion evaluations. The schedule for a typical test day is presented in Table 2.

The walking room was first located at the 70-ft (21 m) position for the first 12 test days, moved to the 30-ft (9 m) position through test day 22, then moved to the 50-ft (15 m) position for the remaining test sessions. Curved floor evaluations were alternated with the flat floor configurations during testing at both the 30- and 50-ft positions.

The changes in ladder configurations was coincidental with the walking room moves (see Section I). The following test conditions were used in the current study:

Rotational rate	4, 5, 6 rpm (0.42, 0.52, 0.63 rad/s)
Psychomotor test stations	40, 75, 80 ft (12, 23, 24 m) radii
Locomotion tests -	
Ladder and elevator	5 to 60 ft (1.5 to 18 m) radii
Walking and cargo handling	30, 50, 70 ft (9, 15, 21 m) radii
Elevator rates	4, 6, 8 ft/s (1.2, 1.8, 2.4 m/s)

Test Subject Selection and Qualification

The personnel used in this program were selected from volunteer engineering personnel. The individuals received no special remuneration or considerations, and continued their principal job assignments when not

Table 2. Typical Test Day

Time	Activity
8:00	Subjects report to RTF emergency medical facility Obtain body weight, pulse rate/blood pressure Don EKG sensors and flight suits Briefing
8:15	<u>Session I</u> Board RTF Perform LCC baselines
9:15	Commence rotation
9:30	Rotation ataxia test
9:45	Psychomotor test (Group 1) DRT - 40 ft station DRT - 78 ft station LCC - 75 ft station Memory - 75 ft station Stromberg - 75 ft station } Subjects assigned to single station (SSP) or sequentially transferring from one station to the next (MSP)
9:45	Gross motor tests I (Group 2) 1st Team - cargo handling 2nd Team - elevator 2nd Team - cargo handling 1st Team - elevator Remove cargo bins (maintenance) 1st Team - walking/cargo transport/pickup/placement 2nd Team - ladder 2nd Team - walking/cargo transport/pickup/placement 1st Team - ladder
11:45	Rotation ataxia test, as scheduled
12:00	Lunch/Subject Rest Period RPM change, as scheduled Install cargo bins
1:15	<u>Session II</u> Gross motor test II (Group 1)
3:15	Cease rotation
3:15	Ataxia (post rotation)
3:30	Return Life Science Labs Obtain body weight Remove sensors Shower/dress
4:00	Debrief test subjects

participating in the rotational program. The initial screening was accomplished by means of a medical history questionnaire to eliminate those individuals with known inadequacies. The remaining individuals were then subjected to the following selection battery to insure the use of healthy test subjects, as well as to comply with local and national medical-legal requirements:

1. Complete FAA Class II type physical examination
2. X-ray of chest and spine
3. Resting and Master's step test EKG
4. Work capacity and maximum oxygen consumption
5. Pulmonary function
6. Orthostatic tolerance
7. Ataxia
8. Psychological testing
9. Sensitivity to anti-motion sickness pharmaceuticals
10. Vision
11. Blood and urine analyses
12. Stress treadmill EKG
13. Audiometry
14. Nystagmic response to caloric irrigation
15. Ocular counterrolling

Items one through ten were performed by NR/SD personnel, while the remaining items were performed by outside laboratories. A total of 40 individuals were screened through the in-house test battery, with a total of 18 individuals being subjected to outside laboratory examinations. These evaluations eliminated an additional three individuals. The characteristics of the final test subject pool of 15 individuals are presented in Table 3. A limit of 40 years of age had been established as a part of the preselection criteria. The individuals fell within the normal range for all of the medical, biochemical,

Table 3. Characteristics of the Final Test Subject Population

Subject Code	Age Yrs	Height In.	(cm)	Weight lb	(kg)	BP mm Hg	Pulse bpm	Fitness Index[a]	Sickness Index[b]
J	24	72	(183)	168	(72)	128/78	72	18	2
K	30	67	(170)	175	(79)	116/80	64	20	3
L	31	72	(183)	171	(78)	150/74	80	12	5
M	38	73	(185)	205	(93)	132/84	72	15	2
O	38	71	(180)	175	(79)	114/88	70	19	4
P	36	70	(179)	175	(79)	118/82	68	16	3
S	31	72	(183)	190	(86)	124/80	64	12	3
T	39	73	(185)	220	(100)	132/76	72	19	1
U	28	70	(179)	177	(79)	130/72	80	15	4
W	36	72	(183)	175	(79)	118/70	72	10	3
X	28	73	(185)	200	(91)	130/90	68	13	3
Z	33	74	(188)	170	(77)	118/70	72	11	5
I	32	75	(191)	220	(100)	138/74	64	16	3
II	36	70	(179)	180	(82)	134/80	80	13	1
III	35	70	(179)	165	(75)	128/76	60	19	1

[a]Percent Grade and Minutes on Treadmill (Reference 11)

Poor	Fair	Good	Very Good	Excellent
10-12	13-15	16-18	19-21	> 21

[b]Rotational Motion Sickness Susceptibility Index
1 very low, 2 low, 3 moderate, 4 high, 5 very high

and vestibular evaluations. None of the subjects was considered excessively over-weight, nor to be hypertensive. As a group, the individuals were classified in the arbitrary category of fair, with respect to physical fitness, as determined by the Balke treadmill test (Reference 11). With the deletion of the three test subjects (L, S, Z), as discussed below, the mean physical fitness of the group was classified as good (16 to 18 minutes and percent grade to reach a pulse of 180 bpm), with four individuals falling into the very good index ($\geq$ 19 minutes). There was no correlation of physical fitness, vestibular responses, or any other parameter which could be utilized to predict susceptibility to motion sickness in the rotational environment. There was a suggestion that those individuals who demonstrated the greatest narrowing of pulse pressure during tilt also demonstrated the greatest susceptibility indices.

Familiarization of the test subjects with the environment was accomplished during rotation at 3, 4, 5, and 6 rpm at the 75-ft (23 m) radius for periods of approximately 60 minutes. During this exposure, test subject Z became extremely nauseated and could not find adequate relief by lying down. A subsequent rotational exposure, while utilizing the Dexedrine/Scopolamine drug combination for motion sickness did not prevent the symptoms and emesis occurred within five minutes. This subject was then removed from the test population. Test subject L remained in the program for approximately two weeks, then withdrew himself due to excessive sensitivity to the rotational environment. Approximately three weeks into the program, test subject S developed a severe respiratory infection, unrelated to the test efforts, and was unable to return to the program. The remaining individuals were divided into three groups and the majority of the rotational testing was accomplished within the group.

Training and Baselines

Test subject training was begun 11 weeks prior to the start of rotational testing. The first nine weeks were devoted to training in the Life Sciences Laboratory area. The training during this period emphasized the LCC, DRT, memory span, Stromberg, and ataxia test battery. Also during this period briefings were held to acquaint the subjects with test purposes and protocols. During the last two weeks of the training phase, the training was conducted at the RTF. It consisted of continual practice on the aforementioned test devices and techniques on the RTF, familiarization of the test subjects with the locomotion cargo tests, rotational familiarization rides, and physiological and performance baselines were obtained.

ANTIMOTION SICKNESS PHARMACEUTICALS

An in-house investigation of the effect of antimotion sickness pharmaceuticals on the state of well-being and psychomotor performance was conducted in association with the contractural efforts. Individual susceptibility or sensitivity to the pharmaceuticals was determined during the course of a normal work day without rotation. The following pharmaceuticals, in opaque green capsules, were provided by Dr. A. Graybiel of the U.S. Naval Aerospace Medical Research Laboratory:

A.	Dramamine	50.0 mg
B.	Scopolamine	0.6 mg
	Dexedrine (Dextro amphetamine sulfate)	10.0 mg
C.	Placebo-Lactose	50.0 mg
D.	Phenergan (Promethazine)	25.0 mg
	Ephedrine	50.0 mg

The rotational evaluations were accomplished by a randomized schedule, with the individual capsule contents unknown to the member of the Medical department who dispensed them. The test sessions were further randomized and scheduled so that no less than 48 hours separated a drug evaluation from any other test sequence.

Motion Sickness Evaluation Results

There were no prerotational side effects reported for either the Dramamine (A) nor the placebo (C). However, 8 of the 15 individuals reported slight euphoria and dry mouth with the Dexedrine/Scopolamine (B) combination, with two of these individuals reporting slight photophobia. Those individuals who reported a reaction to the Phenergan/Ephedrine (D) combination were more vague in their responses. There were eight positive responses as follows: five reporting drowsiness and/or fatigue, one with dry mouth, and two complaining of tachycardia and nervousness. Medical personnel felt that none of the symptoms were of sufficient importance or severity to warrant reduction of the dosage.

The rotational pharmaceutical evaluations all were conducted at 6 rpm, with the test subjects performing psychomotor tasks at the 40 ft (12 m) work station and in the crew module. The details of those tasks and the results will be reported under the specific sections. The test subject was accompanied by a monitor at all stations during these tests and was observed for signs of motion sickness. The test subjects also reported their subjective reactions, which correlated very highly with the report of the observer. The response to the environment with the antimotion sickness pharmaceuticals was as follows, using the scale of Graybiel, et al of Reference 12:

Compound	A	B	C	D
Malaise I	1/11	1/11	1/11	1/11
Malaise II	1/11	2/11	3/11	0/11
Malaise III	3/11	0/11	5/11	0/11
Emesis	0/11	1/11	1/11	1/11

Malaise I includes mild epigastric awareness, flushing, headache, and mild dizziness; Malaise II includes epigastric discomfort, pallor, cold sweating, salivation, drowsiness; Malaise III includes nausea, severe pallor, salivation, and drowsiness; with the pathognomonic state resulting in emesis and retching.

Test subject K developed Malaise III and was removed from the environment, prior to reaching the pathognomonic state with Compound A; suffered a seige of emesis with Compound B, Malaise I with C; but exhibited no symptoms with D. Test subject O had bouts of emesis with Compounds C and D, but reached only Malaise II and I on Compounds A and B, respectively. The complexity of the activities performed makes it very difficult to evaluate these results; however, formulations B and D do offer significant protection in the highly stressful rotational environment, although neither is absolute (Reference 13). Further, while it offered the greatest degree of protection, there was considerable commentary on the hangover or fatigue effect associated with the postrotational effects of formulation D. It is of interest to note that only seven cases of Malaise II, eight cases of Malaise III, and four instances of emesis occurred during the remaining test program, in addition to those listed above. This lowered level of adverse response (11% vs 39% of total man-exposures) is attributable to several factors. For example, the specific tests performed during the pharmaceutical evaluations were more provocative than the regular test program and there was a greater degree of introspection for specific pharmaceutical effects in this phase.

Stress Inventory

The impact of the rotating environment, as modified by the use of anti-motion sickness pharmaceuticals was evaluated with the Composite Mood Adjective Check List (CMACL) (Reference 14). This list is composed of 80 adjectives which may be grouped into approximately 12 factors which indicate the individual's subjective mood in response to stress or other conditions. A check list of 58 adjectives was used in this program which reflect nine mood factors, including aggression, anxiety, concentration, depression, malaise, fatigue, sleepy, sociability, and surgency. This last factor includes the adjectives of carefree, lively, playful, talkative, and witty. The respondent rates each adjective on a nine-point scale, with the lower end of the scale representing a judgment of "not at all" to the upper limit of "definitely." The test was administered to the test subjects a number of times in the nonrotating environment, without pharmaceuticals, to obtain an approximate "control" response. The test was administered to the test subjects following ingestion of one of the pharmaceutical capsules, immediately upon attaining a stable rotational rate of 6 rpm. The test was readministered just prior to facility shut-down at the end of the experimental session.

Stress Inventory Results

Analysis of the results of the CMACL test revealed nine factors which were influenced and dramatically modified by the rotational environment. It had been observed previously that rotation alone produces a mood change. In all instances, the differences between the nonrotating and rotating responses was so great that no statistical treatment was necessary. The mean scores of the test subjects in response to the rotation, as modified by the pharmaceuticals for the nine factors are presented in Tables 4 and 5. The statistical treatment of these data are included in Tables 6 and 7. The differences between the initial test and the results obtained at the end of the rotational period were statistically significant for most factors. It was observed that the lowest initial mood change was obtained with the placebo (C), with the most acute stress response to the environment occurring at the end of the test session in comparison with the pharmaceuticals. All three pharmaceuticals (A, B, D) resulted in a more positive response, with a diminution in negative feelings at the end of the rotational test session, than that obtained with the placebo (C). Dramamine (A) caused a more marked negative response at the beginning of rotation, but tended to result in the fewest negative responses toward the end of the rotational period. The strong initial mood change of the test subjects in response to rotation with the Phenergan/Ephedrine (D) combination tended to remain stable throughout the rotational exposure. The rotational stimulus with the Scopolamine/Dexedrine combination (B) produced a slight initial reaction, and produced the best or least stressful end response. The statistical analyses of the mood factors by the Newman-Kuels technique (Reference 15) revealed that there were highly significant differences for depression, malaise, and sociability, ($\rho \leq .01$) with significant differences for aggression and anxiety ($\rho \leq .05$), especially in comparison of the other pharmaceuticals to the placebo. (See Table 7.)

Reading Performance

In an effort to assess the impact of the environment and the antimotion sickness pharmaceuticals on the test subjects' reading, vocabulary, and comprehension ability, one of three versions of a standardized reading test was administered in the crew module near the end of a 6 rpm rotational period (Reference 16). A second version of the test was administered during an alternate session to evaluate the impact of head movements on reading skills. The question page and answer sheet were placed on desks 90 degrees from each other, to force the test subject to rotate his head from one to the other.

Table 4. Effect of Pharmaceuticals on Nine Mood Factors During Rotation

Factor	Possible Scores[b]	Control	A[a]		B		C		D	
			1st	2nd	1st	2nd	1st	2nd	1st	2nd
Aggression	6-54	6.7	11.0	7.9	9.4	8.8	8.1	12.7	10.3	9.4
Anxiety	7-63	13.3	19.1	16.4	14.7	18.6	14.7	19.4	19.3	18.8
Concentration	9-81	48.3	39.9	39.1	42.4	38.0	43.7	34.0	42.8	38.1
Depression	12-108	24.3	28.0	25.2	22.9	23.9	23.0	28.3	29.7	25.2
Malaise	3-27	4.0	7.8	9.0	7.4	7.6	5.8	12.6	8.7	9.9
Fatigue	8-72	13.7	25.7	25.7	28.6	29.2	26.0	29.9	23.9	29.1
Sleepy	4-36	4.9	12.7	16.4	11.7	14.9	12.6	16.2	11.0	13.6
Sociability	4-36	19.9	12.6	11.4	9.7	13.7	13.3	8.7	11.7	10.9
Surgency	5-45	28.0	17.0	7.0	17.7	17.3	19.9	14.1	19.8	17.4

[a]A - Dramamine, B - Dexedrine/Scopolamine, C - Placebo, D - Phenergan/Ephedrine
[b]Scores based on subjective scoring of adjectives between 1 ("not at all") to 9 ("definitely").

Table 5. Effect of Pharmaceuticals and Trials on Mood Factors During Rotation

Trial		Mood Factors								
		Aggression	Anxiety	Concentration	Depression	Malaise	Fatigue	Sleepy	Social	Surgency
1st	Mean	9.72	16.94	42.47	25.89	7.42	25.33	11.97	11.81	18.61
	SD	4.86	6.66	10.87	8.89	3.43	9.41	6.01	5.16	8.08
	N	36	36	36	36	36	36	36	36	36
2nd	Mean	9.94	18.29	37.41	25.53	9.78	29.21	15.26	11.15	16.47
	SD	5.69	6.68	12.79	8.51	5.81	9.81	7.04	5.87	8.73
	N	36	36	36	36	36	36	36	36	36
Pharma-ceutical										
A	Mean	9.44	17.74	40.38	26.61	8.39	27.14	14.52	11.97	17.00
	SD	5.23	6.65	8.81	10.05	3.68	9.35	6.68	6.19	8.97
	N	18	18	18	18	18	18	18	18	18
B	Mean	9.11	16.61	40.22	23.11	7.56	27.50	13.28	11.67	17.00
	SD	4.06	6.07	16.29	4.91	4.38	11.42	7.46	4.72	9.15
	N	18	18	18	18	18	18	18	18	18
C	Mean	10.39	17.06	38.83	25.67	9.17	27.94	14.39	10.44	17.00
	SD	6.39	6.73	13.14	8.89	6.25	10.24	7.20	5.22	8.92
	N	18	18	18	18	18	18	18	18	18
D	Mean	10.39	19.06	40.33	26.89	9.28	26.50	12.28	11.28	18.61
	SD	5.40	7.42	9.47	10.12	5.07	8.51	5.68	5.86	7.4
	N	18	18	18	18	18	18	18	18	18

See Table 5 for Key to Pharmaceuticals and scores

Table 6. Analysis of Variance of Mood Factors

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
AGGRESSION					
S	1168.867	8	146.108		
D	23.300	3	7.767	0.657	-
SD	283.703	24	11.821		
T	0.867	1	0.867	0.284	-
ST	24.334	8	3.042		
DT	138.445	3	46.148	3.473	0.05
SDT	318.856	24	13.286		
Total	1958.371	71			
ANXIETY					
S	1719.636	8	214.954		
D	61.429	3	20.476	0.787	-
SD	623.229	24	25.968		
T	32.535	1	32.535	1.490	-
ST	174.684	8	21.836		
DT	173.251	3	57.750	3.858	0.025
SDT	359.206	24	14.967		
Total	3143.970	71			
CONCENTRATION					
S	5113.254	8	639.157		
D	29.713	3	9.904	0.073	-
SD	3226.990	24	134.458		
T	461.068	1	461.068	7.096	0.05
ST	519.737	8	64.967		
DT	162.845	3	54.282	1.620	-
SDT	804.163	24	33.507		
Total	10317.762	71			
DEPRESSION					
S	3326.626	8	415.828		
D	190.195	3	63.398	1.537	-
SD	989.350	24	41.223		
T	2.384	1	2.384	0.086	-
ST	219.632	8	27.454	6.241	0.005
DT	250.395	3	83.465		
SDT	320.950	24	13.373		
Total	5299.523	71			
FATIGUE					
S	3221.779	8	402.722		
D	20.096	3	6.699	0.068	-
SD	2330.858	24	97.119		
T	270.668	1	270.668	4.811	0.10
ST	450.051	8	56.256		
DT	12.807	3	4.269	0.237	-
SDT	430.949	24	17.956		
Total	6737.203	71			

Table 6. Analysis of Variance of Mood Factors (Cont)

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
MALAISE					
S	762.194	8	95.274		
D	34.486	3	11.495	0.861	-
SD	320.139	24	13.339		
T	100.347	1	100.347	4.084	0.10
ST	196.528	8	24.566		
DT	120.042	3	40.014	6.017	0.005
SDT	159.583	24	6.649		
Total	1693.319	71			
SLEEPY					
S[a]	1537.539	8	192.192		
D	59.829	3	19.943	0.504	-
SD	947.925	24	39.497		
T	194.702	1	194.702	6.560	0.05
ST	237.417	8	29.677		
DT	3.884	3	1.295	0.146	-
SDT	211.875	24	8.828		
Total	3193.170	71			
SOCIABILITY					
S	1247.689	8	155.961		
D	17.718	3	5.906	0.310	-
SD	460.890	24	19.204		
T	15.680	1	15.680	3.418	0.10
ST	36.690	8	4.586		
DT	128.840	3	42.947	5.948	0.005
SDT	173.270	24	7.220		
Total	2080.775	71			
SURGENCY					
S	4016.000	8	502.000		
D	31.153	3	10.384	0.507	-
SD	491.222	24	20.468		
T	82.347	1	82.347	11.917	0.001
ST	55.278	8	6.910		
DT	93.264	3	31.088	2.777	0.10
SDT	268.611	24	11.192		
Total	5037.863	71			

Key -

Factors	Levels
S - Test Subjects	1 = U, 2 = 1, 3 = K, 4 = W, 5 = P, 6 = M, 7 = O, 8 = J, 9 = X
D - Drugs	1 = Placebo, 2 = Dramamine, 3 = Scopolamine/Dexedrine, 4 = Phenergan/Ephedrine
T - Trials	1 = Initial, 2 = Last

Table 7. Newman-Kuels Analysis of Mood Factors Relative to Pharmaceutical/Trial Combinations

Aggression							
	D1T1	D3T2	D4T2	D3T1	D4T1	D2T1	D1T2
D2T2	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	*
D1T1	---	N.S.	N.S.	N.S.	N.S.	N.S.	*
D3T2		---	N.S.	N.S.	N.S.	N.S.	*
Anxiety							
	D1T1	D2T2	D3T2	D4T2	D2T1	D4T1	D1T2
D3T1	N.S.	N.S.	*	*	*	*	*
D1T1	---	N.S.	*	*	*	*	*
Depression							
	D1T1	D3T2	D2T2	D4T2	D2T1	D1T2	D4T1
D3T1	N.S.	N.S.	N.S.	N.S.	**	**	**
D1T1	---	N.S.	N.S.	N.S.	**	**	**
D3T2		---	N.S.	N.S.	*	*	**
D2T2			---	N.S.	N.S.	N.S.	**
D4T2				---	N.S.	N.S.	**
Malaise							
	D3T1	D3T2	D2T1	D4T1	D2T2	D4T2	D1T2
D1T1	N.S.	N.S.	N.S.	*	*	**	**
D3T1	---	N.S.	N.S.	N.S.	N.S.	N.S.	**
D3T2		---	N.S.	N.S.	N.S.	N.S.	*
D2T1			---	N.S.	N.S.	N.S.	**
D4T1				---	N.S.	N.S.	**
D2T2					---	N.S.	**
D4T2						---	**
Sociability							
	D3T1	D4T2	D2T2	D4T1	D2T1	D1T1	D3T2
D1T2	N.S.	*	*	*	*	**	**
D3T1	---	N.S.	N.S.	N.S.	*	**	**
D4T2		---	N.S.	N.S.	N.S.	N.S.	*

[a]See Table 6 for Key
*Significant at the 0.05 level
**Significant at the 0.01 level
NS Not significant

The various sections of the test were timed and controlled by a test monitor. The test grades were compared to a nonrotational, nonpharmaceutical baseline.

Reading Performance Results

The mean reading scores for vocabulary, comprehension, and totals are presented in Table 8. The head motions produced a consistent decrease in both vocabulary and comprehension, regardless of the pharmaceutical combination employed. An investigation of the test attempts revealed that there was no reduction in effort, rather an increase in incorrect responses. While most of the test subjects were able to decrease the magnitude of the head movements, there were at least three individuals who were able to so orient themselves, during the 90-degree dispersion of question and answer sheets, that they were able to avoid all significant head motions. Also, Test Subject II was highly resistant to the various stimuli of the rotational environment and did not respond to the effects of head motions. While there are insufficient combinations and repeat tests to permit statistical handling of these data, it was observed that the Scopolamine/Dexedrine combination (B) resulted in consistently lower scores, either with or without head movements. The decrease tended to relate more to comprehension than to vocabulary in the static test, but reversed during head motions. The Ephedrine/Phenergan combination (D) appeared to provide some protection during the quiescent portions of the test but resulted in the greatest decrement during head motions. The Dramamine (A) and placebo (C) results, with or without head motion, were mixed, with the changes being quite small. These results suggest that there may be a pharmaceutical interaction which is more significant than rotation, but these are insufficient data to confirm this indication. There did not appear to be a significant correlation of reading skill with the motion sickness susceptibility index.

Stromberg Dexterity Test

These tests were conducted in the crew module in conjunction with the pharmaceutical evaluation to determine the effectiveness of the pharmaceuticals in alleviating the effects of rotation. This test was utilized because it involves fairly rapid head motions as the pegs are moved from one side of the test board to another. These head motions were expected to be moderately provocative at 6 rpm, consequently allowing a comparison of the effectiveness of the pharmaceuticals. In addition, performance was compared at the three orientations, pro-spin, radial, and anti-spin, with nonrotation baselines. This test had been found to be responsive to the effects of rotation, resulting in an eight percent decrease in performance speed at rotational rates to 5 rpm (Reference 8). Eleven test subjects were utilized in this test program. Each test subject performed the test on two of his four pharmaceutical test runs, alternating with the days when he did not perform the reading test.

Table 8. Effect of Anti-Motion Sickness Pharmaceuticals and Head Motions on Reading Skills While Rotating

Test Subject	Test Condition	Test[a] Form	Vocabulary A	Vocabulary B	Vocabulary C	Vocabulary D	Sum Total	Comprehend E	Comprehend F	Comprehend G	Sum Total	Grand Total
J	Baseline	Y	12	12	14	13	51	10	22	36	68	119
	Drug B	X	13	14	13	9	49	6	19	28	53	102
	A + HM	W	10	10	10	10	40	7	15	32	55	95
K	Baseline	X	11	11	12	10	44	7	13	33	53	97
	Drug D	W	12	14	13	11	50	8	15	22	45	95
	C + HM*	Y	7	8	8	8	31	9	20	33	62	93
M	Baseline	X	15	14	15	12	56	9	19	42	70	126
	Drug C	Y	14	15	14	14	57	8	18	38	64	121
	A + HM	W	[illegible]	5	[illegible]	[illegible]	43	10	20	42	72	115
O	Baseline	X	13	12	13	13	51	9	24	37	70	121
	Drug B	W	13	15	12	13	53	12	22	30	64	117
	C + HM	Y	10	13	12	9	44	9	23	34	66	110
P	Baseline	Y	10	11	10	9	40	6	18	36	60	100
	Drug D	W	9	11	10	12	42	9	16	41	66	108
	C + HM	X	5	8	10	9	32	7	18	36	61	93
T	Baseline	Y	12	15	14	13	54	8	19	41	68	122
	Drug C	W	15	14	15	14	58	10	21	38	69	127
	D + HM	X	13	8	11	9	41	12	21	31	64	105
U	Baseline	W	11	12	13	8	44	7	16	38	61	105
	Drug A	X	11	10	13	9	43	7	19	34	60	103
	B + HM	Y	9	7	10	5	31	8	19	35	62	93
W	Baseline	Y	14	15	15	12	56	11	27	40	78	134
	Drug A	W	13	13	13	14	53	13	24	40	77	130
	B + HM*	X	14	14	13	13	54	12	20	43	75	129
X	Baseline	W	13	13	13	9	48	12	20	37	69	117
	Drug D	X	11	13	10	8	42	8	22	40	70	112
	A + HM*	Y	12	15	11	9	47	11	18	38	67	114
I	Baseline	X	15	13	14	12	54	8	20	37	65	119
	Drug D	W	13	15	14	13	55	12	23	36	71	126
	A + HM	Y	9	11	12	12	44	9	22	33	64	108
II	Baseline	Y	6	10	8	6	30	4	8	17	29	59
	Drug A	X	6	8	5	11	30	2	8	24	34	64
	C + HM	W	8	10	11	5	34	1	6	19	26	60

[a]Reference 16
*Avoided Head Motions on All or Part of Test
**Impervious to Rotational Stress
Key - Vocabulary A = Math, B = Science, C = Social Science, D = General;
Comprehension - E = Following Directions, F = Reference Skills, G = Interpretations;
Drugs - A = Dramamine, B = Scopolamine/Dexedrine, C = Placebo,
D = Phenergan/Ephedrine

Each subject performed the test twice at each of the three orientations, either in a anti-spin, radial, and pro-spin sequence or the reverse order.

Stromberg Dexterity Test Results

A summary of the test scores is presented in Table 9. Due to several instances of test subject's motion malaise, the data were not as complete as planned. However, it was possible to make some comparisons of various test conditions by using mean scores corrected for test subject differences. To obtain those differences, the mean scores of a test subject's performance for the pre- and post-test baselines was obtained, and the difference between that score and the group mean score was used as a correction factor for the final comparisons. It should be noted that there was a decline (3.3 percent) in speed between the pre- and post-test baselines, due principally to the infrequency of performance of the test. For this reason, a mean value of the pre- and post-test baselines was utilized for computation of differences.

The results, as summarized in Table 9, reveal an average loss of approximately 11.4 percent in performance time in the rotating environment. Among the pharmaceuticals, only the results with Dramamine are suggestive of poorer performance, while the other compounds appear to be equally effective. It should be remembered that an 8 percent decrease in performance speed was found in earlier studies (Reference 8), and attributed to increasing difficulty of arm motions during rotation up to 5 rpm. The higher rotational rate of 6 rpm employed in this study justifies the conclusion that this factor was principally responsible for the increase in performance time. Also, in agreement with earlier studies, the pro-spin orientation was found to be consistently slower than the other two orientations (Tables 9 and 10).

POSTURAL EQUILIBRIUM EVALUATIONS

All test subjects were evaluated for postural equilibrium, utilizing the ataxia test developed by Fregly and Graybiel (Reference 17). Baselines were obtained by administering the test battery to the test subjects each day until they had achieved consistent scores (see Table 11). Subsequently, the test was administered twice each week to maintain test subject proficiency.

Three basic modes were evaluated as a part of the rotational test program. They were: (1) Evaluation of postural equilibrium during rotation; (2) postrotation evaluation of recovery as a function of rotational rate and the time course of recovery, and; (3) the effect of postrotational head and body motions on the individuals recovery of postural equilibrium.

Table 9. Effect of Pharmaceuticals and Body Orientation on Performance of Stromberg Dexterity Test

Baseline		Pharmaceutical[b]	A	B	C	D
Pre-	Post-Test	Raw	62.3[a]	60.0	58.3	57.3
52.8	54.5	Corrected	62.2	58.3	59.8	59.8
Percent Change		Raw	-16	-12	- 9	- 9
		Corrected	-16	- 9	-11	-11
			Pro-Spin	Radial		Anti-Spin
Orientation			61.1	58.9		58.3

[a]Values are time in seconds to complete one sequence
[b]A = Dramamine, B = Scopolamine/Dexedrine, C = Placebo, D = Phenergan/Ephedrine

Rotational Ataxia

Tests were performed to evaluate several aspects of the rotational environment as reflected in postural equilibrium. Previous studies had indicated a deterioration of postural equilibrium during rotation (Reference 8). The current evaluations were intended to assess the relative influence of rotation rates. In addition, the importance of visual cues was evaluated by performing the tests with eyes open and eyes closed. Finally, postural equilibrium performance was evaluated as a function of rotational experience to provide a measure of short- and longer-term adaptation or accommodation to the stimuli generated in the rotational environment. The test subjects performed the ataxia test battery for the following conditions while rotating:

Walking on floor - eyes open, initial trial	WOFEO I
Sharpened Romberg - eyes open	SREO
Standing on leg - eyes open, right and left	SOLEO-R or -L
Walking on floor - eyes open, second trial	WOFEO II
Walking on floor - eyes closed, initial trial	WOFEC I
Sharpened Romberg - eyes closed	SREC
Standing on leg - eyes closed, right and left	SOLEC-R or -L
Walking on floor - eyes closed, second trial	WOFEC II

All test subjects performed the tests in the hub area on the RTF. The SR and SOL portions of the test battery were performed at a radius of

Table 10. Effect of Orientation and Pharmaceuticals on Stromberg Dexterity Performance

Test Subject	Baseline Values				Pharmaceutical Test Values[c]											
	Pre-Test	Post-Test			A			B			C			D		
		Pro-	Rad-	Anti-	Pro-	Rad-	Anti-	Pro-	Rad-	Anti-	Pro-	Rad-	Anti-	Pro-	Rad-	Anti-
J	104[a] 312[b]	111	116 331	104							115	125 349	109	114	118 347	115
K	103 309	111.5	112 326.5	103				134	130 394	130						
M	118 354	129	124 372	119				127	115 353	116				-	- 384	128
O	103 309	108	102 310	100	128	120 369	121									
P	107 321	109	104 316	103	132	133 386	121	120	110 346	116						
T	111 333	114	118 341	109	132	117 366	117	124	121 365	120						
U	93 279	106	100 300	94							122	117 349	110	117	104 325	104
W	100 300	96	100 306	110							124	121 363	118	119	120 355	116
X	114 342	112	111 345	122				127	116 357	114	115	111 338	112			
1	104 312	114	111 331	106				122	112 348	114	120	114 349	115			
2	104 312	108	102 317	107				-	120 348	112				108	109 337	120
Mean [a] Mean [b]	105 316	111	109 327	107	132	123 375	120	125	118 360	117	119	118 350	113	115	113 345	117
Corrected [b]						373			350			359			346	

[a]Values are time in seconds for 2 trials
[b]Values are time in seconds for 6 trials
[c]See Table 9 for Pharmaceutical Key
-Open cells due to motion sickness

Table 11. Mean Prerotation Baseline Values for Ataxia Test Battery

Test Subject	WOFEC I[a]	SREC[b]	SOLEC-R[b]	SOLEC-L[b]	WOFEC II[a]
J	29.4	180.0	82.69	84.0	28.0
K	28.4	180.0	86.8	90.0	30.0
M	28.8	180.0	87.8	90.0	24.2
O	29.4	180.0	90.0	90.0	29.2
P	30.0	180.0	90.0	90.0	30.0
T	30.0	174.4	90.0	90.0	30.0
U	28.2	180.0	90.0	90.0	29.6
W	30.0	180.0	90.0	90.0	30.0
X	29.2	171.4	86.0	90.0	29.4
I	30.0	180.0	90.0	90.0	29.2
II	23.2	168.4	88.4	84.6	29.0
Possible Score	30.0	180.0	90.0	90.0	30.0
Mean	28.78	177.65	88.32	88.96	28.05
STD. Dev.	3.85	17.94	5.77	5.34	3.78

[a]Number of steps completed in 3 trials
[b]Number of seconds for 3 trials

approximately 20 ft (6 m). The performance of the WOF test began at 20 ft (6 m) and ended at approximately the 10-ft (3 m) radius. The test subjects performed the entire program with either eyes open or eyes closed in accordance with the assignment presented in Table 12. The test personnel were tested twice at each rotational rate, first during the early portion of the program and generally during the last exposure to a given rotational rate. The test protocol consisted of performance of the total test battery, upon attaining a stable rotational rate (designated P1), followed by a second period of performance, following at least two hours of rotation (P2). The protocol for the later day of rotational experience was identical to the tests on the early experience, being designated as P3 and P4, respectively. The test schedule, including the total number of prior rotational exposures for the three groups of test subjects, is presented in Table 13.

Rotational Ataxia Results

The mean values relative to the performance of the ataxia battery during rotation are summarized in Tables 14 and 15, relative to rotational rate and test protocol, with eyes open or closed. Each of the subtests was subjected to an analysis of variance. Each factor whose F-ratio was significant ($\rho \leq .05$) by analysis of variance was further analyzed by the Newman-Kuels technique to determine differences among the means (Reference 15). The analytical results of subtest values are presented in Tables 16 to 21. The data are presented graphically in Figure 12.

The influence of rotational rates produced significantly poorer performance at 6 rpm than at either 4 or 5 rpm, for WOFEO, WOFEC, SREC, and SOLEC, with the results of SOLEO and SREO, although not statistically significant, tending in that direction (see Tables 14 and 15). It may be seen that performance at 4 or 5 rpm did not differ appreciably, but the 6 rpm rate seemed to be a critical point, resulting in marked performance deterioration, even with eyes open.

Reference to Figure 12 and comparison of the statistical analyses reveals the importance of vision in postural equilibrium, as well as the relation of certain other factors, including rotational rate and prior rotational experience. It is obvious from these data that performance aided by visual cues is vastly superior to performance with eyes closed. The fact that with eyes open, postural equilibrium approaches and, in general, reaches a non-rotation level at the 4 and 5 rpm rate and significantly improves at 6 rpm, indicates that significant adaptation (accommodation) does occur. Generally, this adaption requires more than a single exposure/trial. It is quite possible that more complete adaptation over a period of 48 hours continuous exposure at 4 or 5 rpm would result in significant improvement in the eyes closed performance. However, eyes closed performance did not reach 50 percent of non-rotational baseline during any of the ataxia tests, and in most cases

Table 12 Test Subject Assignment for Rotational Ataxia Evaluations

Group	Test Subjects	Eyes Open	Eyes Closed
1	M		X
	O	X	
	P		X
	K		X
2	J	X	
	T	X	
	II		X
3	W	X	
	X		X
	I		X
	U	X	

Table 13. Test Day Assignments for Rotational Ataxia Evaluations

Rate - rpm	4		5		6	
Group \ Test Day	First	Last	First	Last	First	Last
1	13(5)[a]	19(10)	16(8)	25(13)	11(3)	27(15)
2	5(1)	29(15)	25(12)	31(17)	8(3)	30(16)
3	4(2)	29(20)	13(7)	31(22)	9(4)	28(19)

[a] Day of test with number of prior rotational exposures in parenthesis.

was considerably less than this value. Although repeated exposures brought about some improvement, the rate of increase in performance levels was not as rapid as eyes open. For either the eyes open or the eyes closed condition, 6 rpm resulted in significantly poorer performance in all cases.

The Newman-Kuels statistical analyses of the data relative to adaptation are presented in Table 18. The evaluation of short term adaptation within a test day (P1 vs P2 and P3 vs P4) resulted in data that were highly significant for the differences between performance during P4 and P1 ($P \leq .01$), with a significant difference ($P \leq .05$) between P4 and P2 and P3 and P1 for WOFEO. Analyses of rotational rates for WOFEO revealed significant differences ($P \leq .01$) between 6 rpm and both 4 or 5 rpm. The eyes closed performance resulted in significant difference for WOFEC, SREC, and SOLEC. However, there were no significant differences among periods in the case of SREC (Table 18).

Table 14. Effect of Rotational Rate and Vision on Postural Equilibrium During Rotation

Rate - rpm			4	5	6	4	5	6
		EC Baseline	EO			EC		
WOF[a] I	Mean	28.78	22.15	21.7	11.25	6.58	4.25	3.04
	SD	3.85	9.59	9.41	8.36	4.66	3.71	2.51
	N	44	20	20	20	24	24	24
SR[b]	Mean	177.65	174.20	165.10	131.5	55.62	58.25	20.67
	SD	17.94	17.85	37.74	66.36	99.71	50.35	13.03
	N	44	20	20	20	24	24	24
SOL[b] R	Mean	88.32	82.80	84.85	65.1	16.75	13.00	8.92
	SD	5.77	18.61	15.11	29.69	9.50	5.23	2.84
	N	44	20	20	20	24	24	24
SOL[b] L	Mean	88.96	84.25	84.75	68.05	17.79	14.88	9.33
	SD	5.34	17.73	18.15	33.76	10.67	5.23	3.27
	N	44	20	20	20	24	24	24
WOF[b] II	Mean	28.05	21.90	24.30	13.6	7.33	6.63	2.79
	SD	3.78	9.24	9.07	10.33	4.91	3.70	2.08
	N	44	20	20	20	24	24	24
WOF I+II	Mean		22.03	23.00	12.68	6.96	5.44	2.92
	SD		9.29	9.22	9.39	4.75	3.86	2.29
	N		40	40	40	48	48	48

Table 14. Effect of Rotational Rate and Vision on Postural Equilibrium During Rotation (Cont)

Rate - rpm			4	5	6	4	5	6
		EC Baseline	EO			EC		
SOL R+L	Mean		86.89	84.80	67.30	17.27	13.98	9.04
	SD		13.43	16.49	31.68	10.00	5.25	3.04
	N		40	40	40	48	48	48

[a]Scores equal to number of completed steps in three trials
[b]Scores equal to numbers of seconds in three trials
EO = Eyes Open
EC = Eyes Closed

Table 15. Effects of Sequential Exposure and Vision on Postural Equilibrium During Rotation

		EO				EC			
Test		P1	P2	P3	P4	P1	P2	P3	P4
WOF[a] I	Mean	13.47[a]	16.27	21.80	22.60	3.89	3.89	4.39	6.33
	SD	11.02	12.25	7.47	7.26	4.28	3.23	3.15	4.77
	N	15	15	15	15	18	18	18	18
SR[b]	Mean	141.67	165.40	152.20	168.47	48.72	40.72	58.56	50.28
	SD	62.65	33.56	56.57	32.29	55.36	29.75	61.06	50.64
	N	15	15	15	15	18	18	18	18
SOL[b] R	Mean	72.47	77.80	85.07	81.00	12.28	13.67	10.89	14.72
	SD	28.52	22.32	19.11	18.97	6.15	7.17	5.88	8.99
	N	15	15	15	15	18	18	18	18
SOL[b] L	Mean	69.33	83.07	84.53	84.73	11.94	13.44	13.67	16.83
	SD	32.44	20.95	21.17	20.40	5.20	5.98	6.50	11.87
	N	15	15	15	15	18	18	18	18
WOF[a] II	Mean	15.60	18.07	21.73	24.33	3.56	6.11	5.50	7.72
	SD	10.72	13.03	8.21	7.90	3.68	4.68	3.81	4.31
	N	15	15	15	15	18	18	18	18
WOF I+II	Mean	14.53	17.17	21.77	23.47	3.72	4.72	4.94	7.03
	SD	10.74	12.46	7.71	7.51	3.94	3.82	3.48	4.53
	N	30	30	30	30	36	36	36	36
SOL R+L	Mean	70.9	80.43	84.80	82.83	12.11	13.29	12.28	15.78
	SD	30.06	21.44	19.82	19.57	5.62	6.44	6.27	10.43
	N	30	30	30	30	36	36	36	36

[a]Scores equal to number of completed steps in three trials
[b]Scores equal to number of seconds in three trials

Table 16. Analysis of Variance of Eyes Open Ataxia Performance During Rotation

WOFEO

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Ratio	Probabilities
S	3798.717	4	949.679		
P	1521.000	3	507.000	5.929	0.025
SP	1026.083	12	85.507		
T	58.800	1	58.800	1.749	---
ST	134.450	4	33.612		
PT	22.200	3	7.400	0.563	---
SPT	157.550	12	13.129		
V	2599.717	2	1299.858	21.428	0.001
SV	485.283	8	60.660		
PV	303.950	6	50.658	0.788	---
SPV	1541.717	24	64.238		
TV	43.650	2	21.825	0.585	---
STV	298.350	8	37.294		
PTV	154.150	6	25.692	1.067	---
SPTV	577.850	24	24.077		
TOTAL	12723.441	119			

SREO

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	R Ratio	Probabilities
S	27868.230	4	6967.055		
P	6902.664	3	2300.888	1.351	---
SP	20430.156	12	1702.513		
V	20233.730	2	10116.863	2.619	0.20
SV	30898.254	8	3862.282		
PV	4700.930	6	783.488	0.723	---
SPV	25977.699	24	1082.404		
TOTAL	137011.563	59			

Key -

Factors	Levels
S - Subjects	1=0, 2=J, 3=T, 4=W, 5=U
P - Protocol	1=1st Day initial, 2=1st Day final, 3=2nd Day initial, 4=2nd Day final
T - Tests	1=WOF I, 2-WOF II, or 1=SOL-L, 2=SOL-R
V - Rotation rates	1=4 rpm, 2=5 rpm, 3=6 rpm

Table 16. Analysis of Variance of Eyes Open Ataxia Performance During Rotation (Cont)

SOLEO					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Ratio	Probabilities
S	20533.699	4	5133.422		
P	3413.958	3	1137.986	2.955	0.10
SP	4620.164	12	385.014		
T	52.008	1	52.008	0.443	---
ST	469.533	4	117.383		
PT	332.625	3	110.875	0.841	---
SPT	1580.333	12	131.694		
V	9395.816	2	4697.906	2.997	0.20
SV	12536.844	8	1567.105		
PV	1037.116	6	172.853	0.555	---
SPV	7469.859	24	311.244		
TV	142.917	2	71.458	0.955	---
STV	598.417	8	74.802		
PTV	504.950	6	84.158	0.733	---
SPTV	2752.693	24	114.696		
TOTAL	65440.918	119			

Table 17. Analysis of Variance of Eyes Closed Ataxia Performance During Rotation

WOFEC					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Ratio	Probabilities
S	473.313	5	94.662		
P	208.132	3	69.377	8.472	0.005
SP	122.826	15	8.188		
T	33.063	1	33.063	6.404	0.10
ST	25.813	5	5.163		
PT	21.410	3	7.137	2.22	0.20
SPT	48.215	15	3.214		
V	400.042	2	200.021	8.353	0.01
SV	239.458	10	23.946		
PV	109.181	6	18.197	1.727	0.2
SPV	315.986	30	10.533		
TV	42.125	2	21.063	3.736	0.10
STV	56.375	10	5.638		
PTV	32.986	6	5.498	0.592	---
SPTV	278.514	30	9.284		
TOTAL	2407.436	143			

E

Table 17. Analysis of Variance of Eyes Closed Ataxia Performance During Rotation (Cont)

SREC					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Ratio	Probabilities
S	64129.926	5	12825.984		
P	1531.597	3	510.532	0.608	---
SP	12587.305	15	839.154		
V	35994.082	2	17997.039	6.588	0.025
SV	27316.047	10	2731.604		
PV	4416.691	6	736.115	0.552	---
SPV	39971.086	30	1332.369		
TOTAL	185946.563	71			

Key - Factors / Levels

- S - Test subjects: 1=M, 2=P, 3=K, 4=2, 5=X, 6=1
- P - Protocols: 1=1st Day initial, 2=1st Day final, 3=2nd Day initial, 4=2nd Day final
- T - Tests: 1=WOF I, 2-WOF II, or 1=SOL-L, 2=SOL-R
- V - Rotation rates: 1=4 rpm, 2=5 rpm, 3=6 rpm

SOLEC					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F Ratio	Probabilities
S	1016.639	5	203.328		
P	309.417	3	103.139	3.852	0.05
SP	401.583	15	26.772		
T	42.250	1	42.250	0.417	---
ST	505.583	5	101.117		
PT	68.750	3	22.917	1.015	---
SPT	338.417	15	22.561		
V	1646.930	2	823.465	8.616	0.01
SV	955.736	10	95.574		
PV	435.292	6	72.549	2.704	0.05
SPV	804.708	30	26.824		
TV	17.542	2	8.771	0.287	---
STV	305.125	10	30.513		
PTV	138.792	6	23.132	0.634	---
SPTV	1094.529	30	36.484		
TOTAL	8081.277	143			

Table 18. Newman-Kuels Analysis

WOFEO-PROTOCOLS		
	P3	P4
P1	*	**
P2	NS	*

WOFEO-VELOCITY		
	4 rpm	5 rpm
6 rpm	**	**

WOFEC-PROTOCOLS			
	P1	P2	P3
P4	**	*	*

WOFEC-VELOCITIES		
	5 rpm	4 rpm
6 rpm	*	**

SREC-VELOCITIES		
	5 rpm	4 rpm
6 rpm	*	*

Table 18. Newman-Kuels Analysis (Cont)

SOLEC-PROTOCOLS		
	P1	P3
P4	*	*
SOLEC-VELOCITIES		
	5 rpm	4 rpm
6 rpm	*	**

Key
P1 = First day, initial
P2 = First day, final
P3 = Subsequent day, initial
P4 = Subsequent day, final
*Significant at the 0.05 level
**Significant at the 0.01 level

It is noteworthy that an individual frequently was unable to regain his postural equilibrium by relatively large corrective body movements as he does on a stable platform, especially at the 6 rpm rate with eyes closed. This factor is related to the complexity of the dynamic forces generated by body movement in the rotating environment. The results of these analyses indicate the importance of vision in the presence of Coriolis forces and cross-coupled angular accelerations. This factor emphasizes the requirement for tactile and visual aids in passageways on vehicles providing artificial gravity.

Postrotation Ataxia 1

These evaluations were performed to determine more accurately the time course of recovery after exposure to rotation at various rates. In an earlier study (Reference 8), recovery of postural equilibrium was found to proceed rapidly during the first half hour, and by two to four hours postrotation, performance was approaching baseline levels. Although some symptoms related to the rotational exposure continued up to 24 hours, no significant differences in postural equilibrium performance was measurable, other than subjective impressions. The test conditions of the earlier study provided data relative to test subject response immediately after rotation and again two to four hours later, but no information existed for the course of recovery between 30 minutes and 2 hours. Consequently this study was intended to examine that particular period of postrotational responses, including the relationship of rotation rates on recovery.

The combination of tests in this evaluation include the following:

Walking on floor - eyes closed, initial trial	WOFEC I
Sharpened Romberg - eyes closed	SREC
Standing on one leg - eyes closed, right and left	SOLEC-R or -L
Walking on floor - eyes closed, second trial	WOFEC II

The test subjects were divided into three groups with each group performing in one of three periods, following rotation at all three rates. Table 19 specifies test subject assignments, test days, and test protocol.

Table 19. Test Subject Assignment, Time, and Test Day for Postrotation Ataxia 1

Group	Test Subjects	Postrotation Test Periods	Rate-rpm		
			4	5	6
1	M O P	0 to 30[a]	13[b]	17	15
2	K J T II	30 to 60	23	25	8
3	W X I U	60 to 90	19	13	12

[a]Minutes

[b]Day of evaluation

The test was administered to Group 1 immediately after cessation of rotation on the RTF, in that area near the hub. The test was given to Groups 2 and 3 in the Life Sciences Laboratory area. The test was given to each member of the group sequentially, thus requiring up to 30 minutes to administer. This factor controlled the 0 to 30-minute time periods. The order of test administration was randomized on different days to control for both time and individual differences.

Postrotation Ataxia 1 Results

The means and standard deviations for the various subtests for the different test conditions are presented in Table 20. Each subtest was evaluated by an analysis of variance and all test factors with F-Ratio probability $\leq .05$ were further evaluated for significance by the Newman-Kuels procedure (Reference 15). In addition, each of the subtest test condition means were compared with the prerotation baseline by the Dunnette's t technique, to determine the level of significance of the recovery of postural equilibrium (Reference 15). The results of those analyses are given in Tables 21 and 22.

The evaluation of the influence of time after cessation of rotation requires examination of several factors, including those for the different subtests, and comparisons of postrotational periods with the baseline performances. Analysis of WOFEC performance relative to the three postrotational periods indicated a low probability ($P \leq .1$) of differences among them. However, a definite trend was indicated, relative to WOFEC, for improving performance with time. This indication was also supported by the comparison of postrotation recovery with the post test baselines (see Table 25). These data indicate a highly significant difference ($P \leq .01$) between the performance in the 0 to 30-minute postrotation time period, greatly improved performance during the 30 to 60-minute period, with no difference between the 60 to 90-minute period and the post test baseline values (cf. Table 14). Although there were no significant differences for SREC, the poorer performance found in the first hour was completely compensated by the 60 to 90-minute period. Analyses of the results relative to SOLEC performance indicates that among the three postrotational test periods, the 60 to 90-minute period is significantly better ($P \leq .05$) than the 30 to 60-minute period, but not the 0 to 30-minute period. These data and the performance on other subtests suggest a possible decline in postural equilibrium performance between 30 to 60 minutes following cessation of rotation, with rapid and complete improvement after 60 minutes. While not statistically significant, this trend may be seen in Table 20, particularily with respect to the post-5 and 6 rpm performance. Recovery is complete in all instances by the 60 to 90-minute period. It should be noted that more complete adaptation modifies the postrotational recovery time sequence.

Table 20. Effect of Rotational Rate and Time Periods on Ataxia Performance, Postrotation

		Rate rpm			Periods min		
		4	5	6	0-30	30-60	60-90
WOFEC I[a]	Mean	21.27	19.73	19.73	14.58	19.44	26.5
	SD	11.28	8.72	9.11	9.11	9.21	6.37
	N	11	11	11	12	9	12
SREC[b]	Mean	168.09	163.09	171.55	161.25	159.44	180.00
	SD	26.71	42.05	18.86	28.48	45.99	---
	N	11	11	11	12	9	12
SOLEC-R[b]	Mean	87.82	76.09	77.73	79.00	71.55	88.83
	SD	7.24	18.02	27.42	21.5	24.82	4.04
	N	11	11	11	12	9	12
SOLEC-L[b]	Mean	75.91	79.00	79.00	74.17	72.00	86.25
	SD	21.21	15.47	16.67	20.80	18.77	8.76
	N	11	11	11	12	9	12
WOFEC II[a]	Mean	22.82	22.82	24.00	20.25	21.33	28.25
	SD	10.65	7.08	6.77	11.21	5.05	2.63
	N	11	11	11	12	9	12
WOLFEC I +II	Mean	22.41	21.27	21.86	17.42	17.42	27.38
	SD	10.77	7.91	8.13	10.36	7.27	4.85
	N	22	22	22	24	18	24
SOLEC R +L	Mean	81.48	77.55	78.36	76.58	71.78	87.54
	SD	16.93	16.46	22.15	20.83	21.9	6.8
	N	22	22	22	24	18	24

[a]Scores equal to number of completed steps in 3 trials
[b]Scores equal to number of seconds in 3 trials

Table 21. Analysis of Variance of Postrotation Ataxia 1

WOFEC					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
Between Subjects					
P	1132.46	2	566.23	3.249	0.10
S (in groups)	1394.09	8	174.26		
Within Subjects					
V	28.74	2	14.36	0.208	---
PV	378.04	4	94.51	1.375	---
V x S (in groups)	1100.62	16	68.78		
T	158.01	1	158.01	4.263	0.10
VT	53.28	2	26.64	0.718	---
T x S (in groups)	296.55	8	37.06		
VT	5.63	2	2.82	0.103	---
PVT	55.41	4	13.85	0.510	---
VT x S (in groups)	434.34	16	27.14		

SREC					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
Between Subjects					
P	2806.41	2	1403.21	1.152	---
S (in groups)	9739.81	8	1217.47		
Within Subjects					
V	631.06	2	315.53	0.427	---
PV	4174.76	4	1043.62	1.413	---
V x S (in groups)	11817.11	16	738.56		

Table 21. Analysis of Variance of Postrotation Ataxia 1 (Cont)

SOLEC					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
Between Subjects					
P	2800.35	2	1400.18	8.211	0.025
S (in groups)	1364.07	8	170.51		
Within Subjects					
V	471.25	2	253.63	1.124	---
PV	3534.30	4	883.58	3.916	0.025
V x S (in groups)	3609.89	16	225.61		
T	59.38	1	59.38	0.167	---
PT	104.33	2	52.17	0.147	---
T x S (in groups)	2835.74	8	354.46		
VT	652.54	2	326.27	0.856	---
PVT	939.61	4	234.90	0.616	---
VT x S (in groups)	6091.56	16	380.72		

Key - Factors	Levels
S - Test Subjects	1 through 9 (see Table 22)
P - Period, Minutes	1 = 0-30, 2 = 30-60, 3 = 60-90
V - Rotational Rate	1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm
T - Test	1 = WOFEC I, 2 = WOFEC II, or 1 = SOLEC-L, 2 = SOLEC-R

Table 22. Dunnett's t Test Comparison: Baseline Means vs Test Condition Means for Postrotation Ataxia 1

WOFEC						
Period Minutes	Rate rpm 4		5		6	
	WOFEC I	WOFEC II	WOFEC I	WOFEC II	WOFEC I	WOFEC II
0-30	15.93**[a]	13.43**	13.68**	5.68	11.93**	5.43
30-60	5.77	2.1	8.43	10.03*	12.77**	9.10
60-90	-0.57	-1.57	3.93	2.18	2.43	-0.07

Table 22. Dunnett's Test Comparison: Baseline Means vs Test Condition Means for Postrotation Ataxia 1 (Cont)

SOLEC						
Period	Rate rpm 4		5		6	
Minutes	SOLEC-R	SOLEC-L	SOLEC-R	SOLEC-L	SOLEC-R	SOLEC-L
0-30	4.64	30.39*	10.14	8.64	14.14	4.39
30-60	-1.36	-1.36	29.64*	19.98	22.98	31.31**
60-90	-1.36	5.34	2.14	2.89	-1.36	-1.36

a Values are differences (steps or seconds) between test condition and baseline means.

* Significant at the 0.05 level

** Significant at the 0.01 level

The postrotational postural equilibrium was significantly different ($P \leq 0.01$) at 2 hours postrotation following seven days of continuous rotation at 4 rpm. Self-administered tests were reported to be inferior 4 to 6 hours postrotation, but recovery was complete in less than 24 hours. There was no evidence of any differential influence of rotation rates on postrotation recovery except for one significant interaction of 6 rpm and the 30-60 minute period. This result is not supported by any other finding, and therefore, no conclusions can be drawn from it. From the evidence of the evaluations, it is justifiable to conclude that the rotation rates studied do not significantly influence the rate of recovery. Further, results of this series do not support the better performance obtained following exposure to 6 rpm, noted during the postrotation Ataxia 2 evaluations, as discussed below. However, WOFEC II performance was superior to WOFEC I in all cases ($P \leq 0.1$), which supports the findings reported for the postrotation Ataxia 2 tests, indicating that activities involving a large proprioceptive content do aid in the recovery of postural equilibrium.

Postrotation Ataxia 2

These evaluations were performed to provide an assessment of recovery of postural equilibrium after rotation at various rates and in a gross sense, to determine the interaction of the vestibular and the proprioceptive systems on performance. It was intended that these tests answer these questions, as well as provide a basis for recommending possible methods for increasing the rate of recovery following rotation.

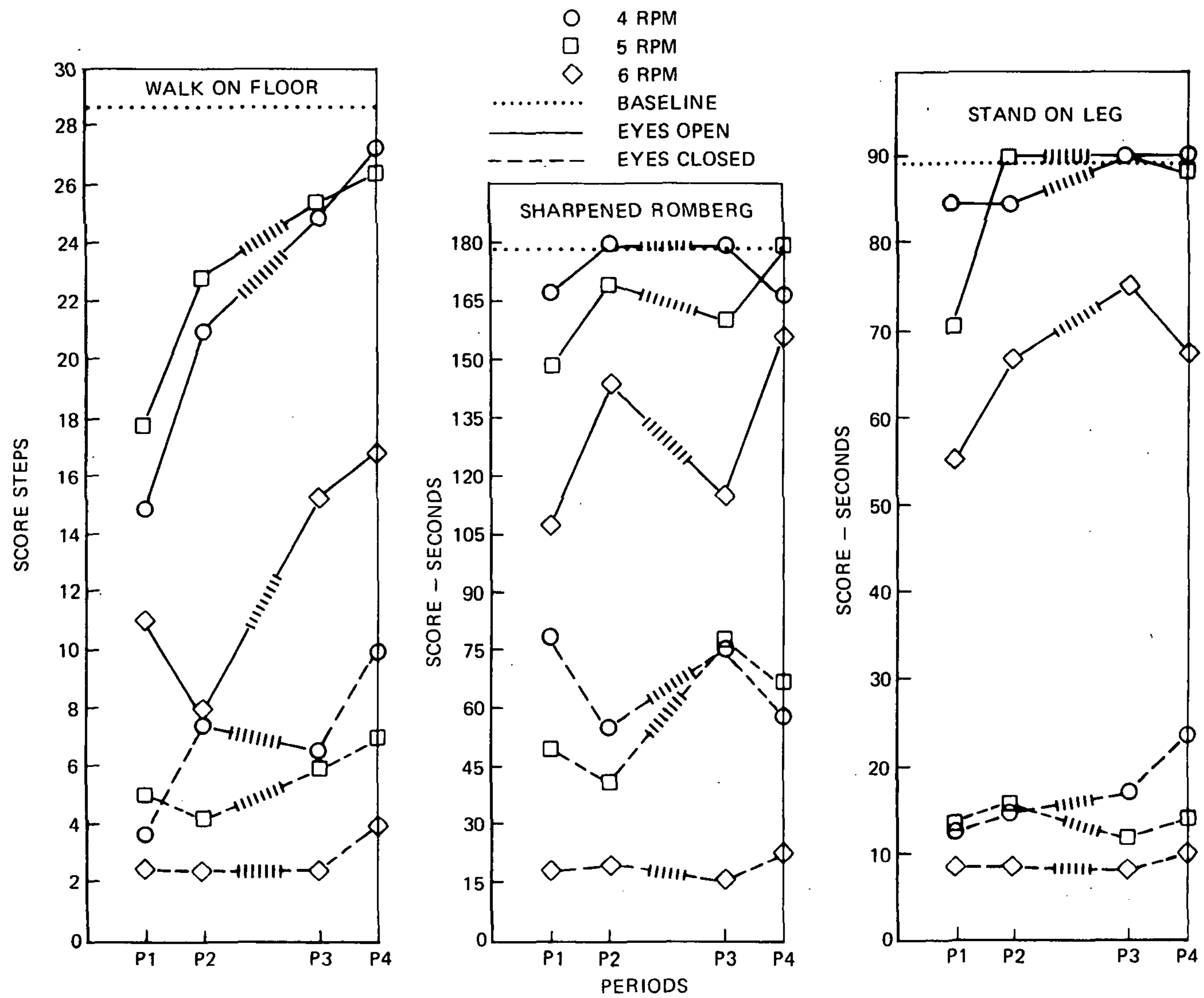

Figure 12. Ataxia Response During Rotation

The test subject population was divided into three groups. These groups performed the Ataxia test after rotation and after having performed either minimum (M1) head and body motions, normal (M2) head and body motions, or patterned (M3) head motions and normal body motions. All of the possible combinations of body (proprioceptive) and head (vestibular) levels of movement are presented in the matrix of Table 23. The three test conditions selected were considered most pertinent and consistent with resource limitations. The fourth condition was obtained by an analysis of the WOFEC I, performed as the first test, and WOFEC II, performed after WOFEC I, SREC, and SOLEC-R and -L. The combination of test conditions for this test were as follows:

Walking on floor - eyes closed initial trial	WOFEC I
Sharpened Romberg - eyes closed	SREC
Standing on one leg - eyes closed, right or left	SOLEC - R or L
Walking on floor - eyes closed, second trial	WOFEC II

The protocol and respective days for exposure to the various test conditions are presented in Table 24. The three conditions of postrotation evaluations are as follows:

Minimum (M1) - Each subject was outfitted with a neck collar prior to despin. He was instructed to sit during the despin and to remain motionless until asked to perform the test battery at the hub area of the RTF. During the test battery he wore the neck collar and was instructed to avoid head movements and body motions between subtests, e.g., he walked backwards to the starting point after a WOFEC trial.

Normal (M2) - Each subject following rotation left the RTF via the stairs and walked to the control room where he performed the test battery. During the time preceding the test he performed all head and body movements normally.

Patterned (M3) - Each subject preceded to the control room as in Normal (M2). However, once there he performed patterned head movements of 90 degrees in four directions, i.e., up, down, right and left, ten times prior to the test battery.

No effort was made to precisely define the various levels, i.e., minimum, normal, etc., but rather they were grossly defined on an operational basis. Also, the dichotomy between propioceptive and vestibular, not to mention other systems such as vision, in relation to postural equilibrium, was

Table 23. Matrix of Possible Body and Head Motion Combinations and the Selected Test Conditions

		Body Movements		
		Minimum	Normal	High
Head Movements	Minimum	(M1)	Not Done	Not Done
	Normal	Not Done	(M2)	WOFEC I Vs II
	Patterned	Not Done	(M3)	Not Done

Table 24. Motion Protocol and Test Day for Postrotation Ataxia 2

Group	Subjects	Movements	rpm / Test Day	4	5	6
1	M O P	Minimum (M1)		19	21	14
2	K J T II	Normal (M2)		5	31	11
3	W X I U	Patterned (M3)		23	4	29

created solely to evaluate the gross importance of these factors on test subject recovery.

Postrotation Ataxia 2 Results

The means and standard deviations for the subtests under various test conditions are presented in Table 25. Each of the ataxia battery subtests was subjected to an analysis of variance. In addition, each test condition mean was compared to the nonrotation baseline for WOFEC and SOLEC to determine level of recovery, using Dunnett's t test (Reference 15). Inasmuch as there were no significant differences for SREC, these data have been omitted. The results of these analyses are presented in Tables 26 and 27.

The comparison among the three conditions, minimum, normal, and patterned, yielded no significant differences for any of the subtests. However, from Table 26 the comparison between WOFEC I and WOFEC II was found to be highly significant ($p \leq 0.01$). This result would support a conclusion that recovery is aided by body movement and that similar movements might be useful in accelerating recovery.

The comparison among rotation rates indicated no significant differences ($p \geq 0.05$), however WOFEC and SOLEC resulted in a probability of ≥ 0.1. Inspection of the data for WOFEC, as well as the other subtests, yielded a most unexpected trend; i.e., performance following 6 rpm was best. One potential explanation for this trend might include attributing it to not being exposed to 6 rpm until several prior exposures at 4 and 5 rpm. Another explanation might be the observed reluctance of some subjects at 6 rpm not noted at 4 and 5 to move about freely and stimulate themselves from the viewpoint of the proprioceptor/vestibular systems. This reluctance may have resulted in less adaption to rotation and therefore less recovery required for the nonrotational evaluations.

The comparison of test condition means with the nonrotation baseline indicated no significant differences for SREC. However, many were found for WOFEC and SOLEC. Examinations of those results tend to follow the analysis of variance. Again, it appears that 6 rpm did result in a smaller decrement in ataxia performance. Whether that is a direct function of rate or a secondary result is not clear as discussed above. Also these comparisons might lead to the conclusion that patterned head movements (M3) did aid in recovery, in that the M3 performance appears less different from baseline performance than did the other conditions (see Tables 14 and 25).

It also appears that the loss of postural equilibrium is significant and could be important to performance in some operational situations. The results of these evaluations appear then to suggest that the more body

Table 25. Effect of Rotational Rate and Movement for Postrotation Ataxia 2

		RPM			Movement[c]		
		4	5	6	M1	M2	M3
WOFEC I[a]	Mean	13.45	12.00	17.09	14.78	11.75	16.67
	SD	8.45	9.85	7.82	7.14	10.41	8.12
	N	11	11	11	9	12	12
SREC[b]	Mean	134.18	124.45	136.90	162.23	109.58	139.58
	SD	75.28	71.40	66.48	51.15	82.36	52.60
	N	11	11	11	9	12	12
SOLEC-R[b]	Mean	65.27	52.45	68.64	62.33	53.67	70.42
	SD	34.24	31.30	17.89	21.75	35.07	25.79
	N	11	11	11	9	12	12
SOLEC-L[b]	Mean	64.73	52.64	68.09	51.67	58.92	71.72
	SD	31.60	32.57	27.65	31.43	34.11	24.53
	N	11	11	11	9	12	12
WOFEC II[a]	Mean	21.27	19.00	25.27	19.78	20.58	24.67
	SD	7.81	9.05	4.00	8.29	8.65	5.11
	N	11	11	11	9	12	12
WOFEC I + II	Mean	17.36	15.50	21.18	17.28	16.17	20.41
	SD	8.89	9.90	7.37	7.93	10.39	7.93
	N	22	22	22	18	24	24
SOLEC R+L	Mean	65.00	52.55	68.36	57.00	56.29	71.38
	SD	32.15	31.17	22.73	25.79	33.94	24.65
	N	22	22	22	18	24	24

a - Scores equal to number of completed steps in 3 trials
b - Scores equal to number of seconds for 3 trials
c - See text

movements (and perhaps head movements) that are made following rotation, the more rapid the recovery of postural equilibrium. Also, 6 rpm appears to be the level at which movement within the environment becomes excessively stimulating, resulting in important changes in behavior and performance. Elucidation of this later point will require further evaluation in additional tests or observations. The prime purpose of these tests, the influence of

F

Table 26. Analysis of Variance of Postrotation Ataxia 2

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
WOFEC					
Between Subjects					
M	221.91	2	110.96	0.671	-----
S (in groups)	1322.01	8	165.25		
Within Subjects					
V	392.84	2	196.42	2.86	0.1
MV	253.49	4	63.37	0.921	-----
V_xS (in groups)	1100.66	16	68.79		
T	847.59	1	847.59	43.49	0.001**
MT	68.01	2	34.	1.74	-----
T_xS (in groups)	155.94	8	19.49		
VT	8.80	2	4.40	0.09	-----
MVT	72.52	4	18.13	0.388	-----
VT_xS (in groups)	746.57	16	46.66		
SREC					
Between Subjects					
M	14278.74	2	7139.37	0.886	-----
S (in groups)	64461.17	8	8057.64		
Within Subjects					
V	2199.29	2	1099.64	0.408	-----
MV	14926.44	4	3731.61	1.385	-----
V_xS (in groups)	43079.67	16	2692.47		

Table 26. Analysis of Variance of Postrotation Ataxia 2 (Cont)

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
SOLEC					
Between Subjects					
M	3138.82	2	1569.41	0.533	-----
S (in groups)	23517.59	8	2939.69		
Within Groups					
V	3252.21	2	1626.10	3.137	0.1
MV	4263.88	4	1065.97	2.056	0.2
VxS (in groups)	8292.34	16	518.27		
T	22.09	1	22.09	0.025	-----
MT	763.15	2	381.58	0.432	-----
TxS (in groups)	7065.91	8	883.23		
VT	.06	2	0.03	----	-----
MVT	155.81	4	38.95	0.117	
VTxS (in groups)	5334.34	16	333.39		

Key -
Factors
- S - Test Subjects: 1 through 9
- M - Movements: 1 = Minimum, 2 = Normal, 3 = Patterned
- V - Rotation Rate: 1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm
- T - Test: 1 = WOFEC I, 2 = WOFEC II or 1 = SOLEC-L, 2 = SOLEC-R

head and body movements, may also require more refined test conditions for a more precise assessment.

PSYCHOMOTOR TESTS

Memory Span

A series of tests was administered to the test subjects in an effort to evaluate the effects of rotational factors on short-term memory. The memory span test performance was compared at the three rotational rates of 4, 5, and 6 rpm, as well as being included in the evaluation of the effect of multistation (MSP) versus single station protocols (SSP) on performance.

Table 27. Dunnett's t Test Comparison: Baseline Mean vs Test Condition Means for Postrotation Ataxia 2

WOFEC						
rpm	4		5		6	
Test	I	II	I	II	I	II
M1[a]	17.17**[b]	13.10**	13.10**	10.43*	10.10*	4.43
M2	12.43**	6.68	21.43**	12.68**	16.18**	3.98
M3	15.43**	3.18	13.93**	6.93	7.43	0.98
SOLEC						
rpm	4		5		6	
Leg	R	L	R	L	R	L
M1[a]	28.98[b]	38.64*	37.64*	50.31**	12.31	21.98
M2	43.89**	34.89*	38.64*	36.14*	22.39	18.14
M3	1.36	1.89	32.64*	25.14	23.39	21.89

[a] Movements (see text)
[b] Values are differences (in steps or seconds) between test and condition and baseline means
* Significant at the 0.05 level
** Significant at the 0.01 level

In addition, the possible modifying effects of antimotion sickness pharmaceuticals on short-term memory and recall was evaluated at the 6 rpm rotational rate. All of the evaluations in this series were conducted in the crew module, with the test subject facing the hub. The test consisted of presenting to the test subject a series of tape-recorded digit spans, starting at a span of three and increasing to ten numbers. Each level of the digit spans consisted of four separate combinations of numbers. These numbers were obtained from a table of random numbers, and prerecorded to minimize number patterns and differences in presentation. Following presentation of each number combination to a test subject, a 10- to 15-second period, depending on the length of the digit span, was allowed for recording of the number by the subject. There was a possible score of 208 for each tape of digit spans.

There were four sets of four tapes each prepared for use during the evaluations. Each of the sets was used for a single portion of the test program. Thus, a different set was used for training, MSP, SSP, and the pharmaceutical evaluations. The use of the tapes within a set by the subjects was balanced and randomized as far as possible.

Each of the 11 test subjects performed the test at the three rotation rates during the MSP testing. The three test subjects, selected to perform the SSP evaluations, also performed the four tapes of the SSP series at the three rotational rates. For the pharmaceutical evaluations, all 11 test subjects performed the test while evaluating each of the four pharmaceutical combinations.

Memory Span Results

The test means for the memory span are given in Table 28. The values in that table represent the sums of the correctly recorded digit spans (i. e., 3 points was given for a 3-digit span, and 7 for a 7-digit span). These values also were corrected for differences, relative to the difficulty of the tapes. This correction factor was obtained by determining the mean performance scores for each tape and the difference from the overall mean for that set of tapes, and then adding or subtracting the factor from the individual test subject's score.

The analysis of variance for the three test conditions is presented in Table 29. A significant result was found among the performance with respect to rotational rates and baselines. The pre-test baseline, representing the fifth and sixth training tapes, was significantly slower than performance at the 4 rpm rate and the post-test baseline ($P \leq .0.05$). This is indicative of continued learning throughout the testing period. This factor, it is believed,

Table 28. Effects of Rotational Rates, Head Motions, and Pharaceuticals on Memory Span

	Baseline Pre-Post		4 rpm	5 rpm	6 rpm
MSP All S_s	112.3[a]	136.0	133.5	127.0	121.8
SSP1			141.5	161.8	149.8
SSP2			154.3	136.8	163.1
SSP3			159.0	142.3	153.0
SSP4			157.7	145.0	151.0
SSP TOTAL	125.0	156.2	152.4	145.8	153.8
MSP Scores For SSP/S_s			153.3	154.3	134.0
Pharmaceuticals[b]	A		B	C	D
	123.2		135.7	137.6	121.8

[a] Values are correct answers (see text)
[b] A = Dramamine, B = Scopolamine/Dexedrine
C = Placebo, D = Phenegran/Ephedrine

Table 29. Analysis of Variance of Memory Span Performance

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
MSP					
S	24182.523	10	2418.252		
V	3929.698	4	982.424	3.12	0.025
SV	12583.146	40	314.579		
TOTAL	40695.363	54			
SSP					
S	4358.387	2	2179.193		
V	437.389	2	218.694	0.4950	- - - -
SV	1767.278	4	441.819		
T	0.250	3	0.083	0.00042	- - - -
ST	1195.833	6	199.305		
VT	1927.500	6	321.250	2.43	0.1
SVT	1591.167	12	132.597		
TOTAL	11277.797	35			
PHARMACEUTICALS					
S	26991.719	8	3373.965		
D	1920.667	3	640.222	1.490	- - - -
SD	10307.832	24	429.493		
TOTAL	39220.216	35			

Key:

Factors	Levels
S - Test subjects	1=U, 2-1, 3=2, 4=K, 5=W, 6=P, 7=M, 8=0, 9=T, 10=J, 11-X (MSP); 1=W, 2-O, 3-T (SSP)
V - Rotation rates	1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm, 4 = 0 rpm (Pretest baseline) 5 = 0 rpm (Post-Test baseline)
T - Trials	1 = SSP1, 2 = SSP2, 3 = SSP3, 4 = SSP4
D - Pharmaceuticals	1 = Dramine, 2 = Scopolamine/Dexedrine 3 = Placebo, 4 = Phenergan/Ephedrine

confounded the rotational evaluations. No other significant findings were found. The decreasing performance with increasing rotation rates (cf MSP means) did not reach the .05 level of significance, but is suggestive of what may be occurring.

No significant results were obtained for the SSP testing. However, the fact that learning was still occurring during the rotational testing, possibly obscured any rotational effects. This observation also relates to a comparison of test means, in that performance of 6 rpm tended to be lower for most of the test conditions. However, in the case of the three SSP test subjects, all sources were comparable, with the exception of the 6 rpm MSP performance (see Table 28). This result may be indicative first of the increased provocativeness of 6 rpm over the lower rates, and second, the effect of stimulation associated with the station changes during MSP as contrasted to SSP performance

The results of the pharmaceutical evaluations indicate no statistically significant differences among the pharmaceuticals (Table 29). However, performance after all of the pharmaceuticals, including the placebo, was found to be significantly lower than the post-test baseline ($P \leq .05$). This result would tend to support a conclusion that exposure of individuals to 6 rpm causes a decrease in short-term memory capability. Also, of the various pharmaceuticals evaluated, none alleviated the influence of 6 rpm. The data do suggest that the Phenergran/Ephedren combination and Dramamine may tend to lower cognitive functions, such as short-term memory, due to their tranquilizing or sedative-like side effects. Other studies related to the effects of the pharmaceuticals may shed additional light on that possibility.

Langley Complex Coordinator Evaluations

Langley complex coordinator (LCC) was used to evaluate complex psychomotor performance involving coordination of all four limbs, with two levels of cue discrimination. The task was evaluated for influence of rotation rates, multiple station protocol (MSP) versus single station protocol (SSP) during a session, and intervening head movements. In addition, the influence of rotation of 6 rpm with selected antimotion sickness pharmaceuticals on LCC performance was evaluated.

The task was performed in the crew module of the RTF, with the test subject oriented in the radial direction, facing the hub. There were two LCC's, one equipped with the standard mode program drum, and the other with the complex mix mode program drum. The standard (STD) mode involved straight matching of four sets of stimulus lights with the four limb controlled response lights. The complex mix mode (CM) required the test subject to determine the correction factors for light cancellation by reference to additional stimulus lights. The correction factor might require that the alignments of the limb-controlled lights be displaced by one or two places from the indicator light in order to obtain a match. It was expected that the CM mode would have a higher cognitive factor, and thus would better reflect rotational influences on that area of psychomotor performance than would the standard mode.

During the MSP, 11 subjects performed both the STD and CM. Five trials were performed on the STD LCC. The first trial was considered a warmup test, but it was included in the analysis. Two trials were performed with the CM. All subjects performed the task during all three rotation rates.

Three test subjects were evaluated while performing the LCC tasks during each of the SSP subperiods. Each subject performed four STD trials and two CM trials in each of the subperiods 1, 2, and 4. During the SSP subperiod 3, the test subjects first performed three STD trials then performed a series of ten head motion (HM) sets, followed by three additional STD trials and three CM trials. Each HM set included a forward movement of the head to chin on chest positions, backward head movement until the test subject viewed a spot on the ceiling, a lateral movement to place head on the right shoulder, and then place the head on the left shoulder.

The evaluation of antimotion sickness pharmaceuticals on LCC performance was completed by nine test subjects for the STD mode, and eight test subjects with the CM mode. These test subjects performed the task identically with the MSP procedures after having received one of the pharmaceuticals. All evaluations in this last series were conducted at 6 rpm.

LCC Results

The pre-and postrotation baseline values are presented in Table 30. The results of the LCC psychomotor test performance are presented in Tables 31 through 35. The means and standard deviations of both MSP and SSP performance with respect to rotational rate, test complexity, test protocols, and pharmaceuticals are presented in Tables 31 and 32.

It will be noted in Table 30 that the postrotational baseline performance times obtained at the end of the program were better than the pretest baselines, indicating a training effect during the test program. Those parameters found to be significant by an analysis at variance were further subjected to analysis by the Newman-Kuels technique (Reference 15) for interaction significance. It may be seen in Table 35 that the performance of the STD mode during MSP was significantly ($P \leq 0.01$) slower at the 5 and 6 rpm rates

Table 30. Pre- and Postrotation Baseline Values for LCC Performance

	Pretest		Posttest	
Subjects	STD	CM	STD	CM
J	80.6[a]	149.5	74.6	123.5
K	96.2	189.	91.2	184.5
M	94.6	- - -	103.	- - -
O	92.	176.	96.2	174.5
P	93.2	212.5	96.6	186.
T	104.2	164	100.2	161.5
U	73.2	135.	67.8	125.
W	87.4	157.5	84.8	145.
X	95.4	207.5	92.1	168.5
I	91.4	153.	88.4	143.5
II	111.8	216.5	95.	221.5
Mean	92.7	176.1	89.6	163.4

[a] Time in Seconds

Table 31. **Effect of Rotational Rate and Test Complexity on LCC Performance**

MSP

Mode		Pre- (Baselines)	Post- (Baselines)	WU	T 1	T 2	T 3	T 4	4 rpm	5 rpm	6 rpm	Total
STD	Mean	92.73[a]	89.63	98.10	97.10	94.24	91.23	94.54	93.11	97.07	96.56	95.58
	SD	10.54	10.93	11.36	10.90	10.94	16.82	9.67	9.45	11.28	10.54	
	N	55	55	33	33	33	33	55	55	55	55	
CM	Mean	175.80	163.35	--	151.69	173.00	--	--	173.06	179.67	174.24	175.66
	SD	28.66	29.90		66.56	27.06			33.38	23.39	26.76	
	N	20	20		30	30			20	20	20	

SSP

Mode		T 1	T 2	T 3	T 4	4 rpm	5 rpm	6 rpm	P 1	P 2	P 4
STD	Mean	85.42[a]	83.86	83.34	82.05	82.11	82.89	86.07	82.39	84.57	84.37
	SD	15.38	14.64	11.94	11.95	12.26	13.64	14.42	11.20	14.71	14.57
	N	27	27	27	27	36	36	36	36	36	36
CM	Mean	156.12	113.82	--	--	151.30	130.59	162.31	152.50	154.19	157.49
	SD	30.63	74.18	--	--	25.91	30.70	36.34	28.61	32.53	33.71
	N	27	27			18	18	18	18	18	18

SSP 3 (WITH HEAD MOTIONS)

Mode		T 1	T 2	T 3	4 rpm	5 rpm	6 rpm
STD	Mean	85.49[a]	84.56	80.77	83.22	83.51	84.08
	SD	13.76	15.51	13.49	12.87	15.60	14.72
	N	9	9	9	9	9	9
CM	Mean	157.39	158.97	---	156.30	153.73	164.50
	SD	34.30	38.95		39.74	40.95	31.32
	N	9	9		6	6	6

[a] Performance time in seconds to complete one sequence

Key - STD = Standard Mode; CM = Complex mix mode
T = Trial; WU = Warmup trial; P = Performance protocol
MSP = Multiple station protocol; SSP = Single station protocol

Table 32. Effects of Trials, Test Complexity, and Pharmaceuticals on LCC Performance at 6 rpm

Mode		WU	T 1	T 2	T 3	T 4	A[b]	B	C	D
STD	Mean	97.33[a]	96.78	95.67	94.88	94.25	99.03	93.99	95.26	94.83
	SD	11.10	11.40	12.38	13.82	12.49	15.02	10.74	10.88	11.4
	N	36	36	36	36	36	45	45	45	45
CM	Mean	--	177.47	174.81	--	--	180.63	174.81	171.74	177.38
	SD		26.15	26.72			26.73	33.16	22.09	23.38
	N		32	32			16	16	16	16

[a] Performance time in seconds to complete one sequence

[b] A = Dramamine, B = Scopolamine/Dexedrine, C = Placebo, D = Phenergan/Ephedrine

when compared to the postrotational test baseline values. There were no other significant differences relative to either the prerotational test baseline, the 4 rpm value nor inter-rate values. Analyses with respect to trials for the STD mode during MSP testing revealed significant differences among the values for warmup and trials 2, 3, 4 ($P \leq .01$); and a similar difference between T1 and T2, with only a level of .05 significance between T1 and T4. These results indicate an effect of rotation on the performance of this test. However, there was no significant difference for SSP performance with head motions in comparison to the baseline values, indicating that the effect seen during MSP STD mode testing might be related to the stimulus of changing stations. The SSP3-STD mode performance of T3 was found to be significantly faster ($P \leq .05$) than T1 or T2.

There were no highly significant findings in these tests among the antimotion sickness pharmaceuticals and placebo. As in the tests discussed above, there was a trend for improvement of performance with repeated trials ($P \leq .10$). In addition, there was a significant interaction between pharmaceuticals and trials for the CM mode ($P \leq .05$). Examination of the data revealed that this significance was related to poorer performance of Trial 1 with Dramamine, in contrast to Trials 1 and 2 with the placebo and Scopalamine/Dexedrine combinations, respectively.

The results of these tests suggest that possibly the required concentration and lack of movement associated with performance on the LCC prevented the occurance of any significant interaction of rotation and performance. This observation is substantiated in the effect of moving from one station to another, as well as the effect of repeated trials which result in continuing improvement. The poorer performance during rotation, in comparison to the post-rotational test baseline, possibly is indicative of the residual effects of the stimulus of moving into the test station.

Decision Response Time Device Evaluations

The decision response time (DRT) device was used in the test program to provide a basis for evaluation of psychomotor tasks involving information processing and reaction times. The DRT provided a basis for comparison of performance as influenced by rotation rates, body orientation, head movements, multiple station vs single station protocol (MSP/SSP), and selected antimotion sickness pharmaceuticals. Training on the device was begun 11 weeks prior to rotational testing. Baseline values were established for the prerotational tests utilizing the results of the last two performances on the DRT obtained on the static RTF. The postrotational test baselines were obtained on the facility in the nonrotating condition, using the five couch orientations, head motions, and an evaluation of fatigue. The first two techniques are discussed below. The latter test was conducted as follows: The test subject completed two sequences with the DRT set on Mode A (code on right hand display), followed by three additional sequences at this setting; the DRT was switched to Mode B (left hand display) and the sequence was repeated. The performance was evaluated for the mean time to complete the first set of two sequences and the second set of three sequences under both conditions, then the average performance on each of the first, second and third trials was calculated. An increase in performance time between sessions and between trials would be indicative of decreased performance due to fatigue.

The use of the DRT during rotational testing must be considered under three separate test techniques, standard mode (STD), head motions mode (HM), and pharmaceutical evaluations. Each technique will be discussed separately within this section.

Standard Mode

For the STD mode, 11 subjects were used. Each subject performed two 25-problem sets at each of the five couch orientations (90 degree pro-spin, 45 degree pro-spin, axial, 45 degree anti-spin, and 90 degree anti-spin). Each subject did this task at both the 40- and the 80-foot stations.

Head Motion Mode

This mode was intended to evaluate the influence of head motions and visual cues on task performance. To accomplish this, each subject with the couch in the axial orientation performed two warmup trials (Hx), and then made a rapid head motion (80 degrees), with his eyes open, from one DRT display to the other and then performed two more trials (HO_1). After this, the test subject rested 60 seconds to allow the effects of the head motion to dissipate. Another head motion, in the opposite direction, was made with eyes open (HO_2) and two more trials were performed. Following this series, the 60-second rest was allowed, followed by two more head motion-task trials, except that the later two were performed with eyes closed (HC_1 and HC_2).

The head motion on the standard modes were performed by all test subjects at all rotation rates and both radii (with the exception of 80 ft, 6 rpm) and under both MSP and SSP test conditions.

Table 33. Analysis of Variance for LCC Standard Mode

MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
S	21777.660	10	2177.766	7.826	0.001
T	603.008	4	150.752		
ST	770.479	40	19.262	6.324	0.001
V	2219.737	4	554.934		
SV	3509.965	40	87.749	0.949	
TV	280.466	16	17.529		
STV	2952.278	160	18.452		
TOTAL	32113.586	274			

MSP/SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
S	19204.016	2	9602.008	1.164	
T	141.298	3	47.099		
ST	242.632	6	40.439	3.473	0.20
V	265.584	2	132.792		
SV	152.909	4	38.227	1.340	
TV	122.841	6	20.473		
STV	183.258	12	15.272	0.780	
P	169.652	3	56.551		
SP	478.672	6	79.779	0.457	
TP	49.953	9	5.550		
STP	218.307	18	12.128	0.722	
VP	322.585	6	53.764		
SVP	893.517	12	74.460	1.342	
TVP	642.603	18	35.700		
STVP	957.089	36	26.586		
TOTAL	24044.895				

Table 33. Analysis of Variance for LCC Standard Mode (Cont)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probabilities
With Head Motions (SSP3)					
S	8610.418	2	4305.207	13.767	0.025
T	336.908	2	168.454		
ST	48.942	4	12.235	3.287	0.20
P	30.978	1	30.978		
SP	14.451	2	7.226	1.00	
TP	46.434	2	23.217		
STP	92.824	4	23.206	1.774	
V	21.737	2	10.868		
SV	24.504	4	6.126	0.355	
TV	63.422	4	15.855		
STV	356.705	8	44.588	0.281	
PV	10.744	2	5.372		
SPV	76.451	4	19.113	0.705	
TPV	47.096	4	11.774		
STPV	133.504	8	16.688		
TOTAL	9915.094	53			
Pharmaceutical Evaluations					
S	18211.012	8	2276.376	2.137	0.10
T	236.480	4	59.120		
ST	884.916	32	27.654	1.146	
D	670.843	3	223.614		
SD	4681.066	24	195.044	0.696	
TD	153.890	12	12.824		
STD	1768.698	96	18.424		
TOTAL	26606.891	179			

Key:

Factors	Levels
S - Subjects	1 = U, 2 = 1, 3 = 2, 4 = K, 5 = W, 6 = P, 7 = M, 8 = 0, 9 = T, 10 = J, 11 = X
T - Trials	1 = Warmup, 2 = STD 1, 3 = STD 2, 4 = STD 3, 5 = STD 4
V - Rotation Rate	1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm, 4 = Prerotation Baseline, 5 = Postrotation baseline
P - Protocol	1 = MSP; 2 = SSP_1; 3 = SSP_2; 4 = SSP3, with Head Motions, 5 = SSP4
D - Pharmaceutical	1 = Dramamine, 2 = Scopolamine/Dexedrine, 3 = Placebo, 4 = Phenergan/Ephedrine

Table 34. Analysis of Variance for LCC Complex Mode

MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F - Ratio	Probabilities
S	64041.039	9	7115.668	3.598	0.10
T	365.572	1	365.572		
ST	914.349	9	101.594	3.669	0.025
V	2960.090	4	740.022		
SV	7260.629	36	201.684	0.503	
V	282.590	4	70.647		
STV	5047.309	36	140.203		
TOTAL	80871.438	99			

MSP/SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F - Ratio	Probabilities
S	59634.855	2	29817.426	6.271	0.05
P	1306.023	3	435.341		
SP	416.489	6	69.415	0.963	
T	98.235	1	98.235		
ST	203.921	2	101.960	0.338	
PT	129.177	3	43.059		
SPT	762.391	6	127.065	4.829	0.10
V	1539.010	2	769.505		
SV	637.317	4	159.329	2.404	0.10
PV	791.153	6	131.859		
SPV	657.926	12	54.827	0.302	
TV	438.621	2	219.311		
STV	2904.156	4	726.039	1.180	
PTV	416.480	6	69.413		
SPTV	705.871	12	58.823		
TOTAL	70641.375	71			

Table 34. Analysis of Variance for LCC Complex Mode (Cont)

With Head Motions (SSP3)					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F- Ratio	Probability
S	36652.008	2	18326.004	0.250	
T	39.691	1	39.691		
ST	316.361	2	158.181	0.153	
P	4.271	1	4.271		
SP	55.554	2	27.777	8.833	0.10
TP	121.735	1	121.735		
STP	27.561	2	13.780	4.513	0.10
V	1291.704	2	645.852		
SV	572.393	4	143.098	0.013	
TV	1.295	2	0.648		
STV	191.263	4	47.816	0.270	
PV	77.262	2	38.631		
SPV	572.150	4	143.037	4.250	0.20
TPV	651.824	2	325.912		
STPV	306.701	4	76.675		
TOTAL	40881.746	35			

Pharmaceutical Evaluations					
Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F - Ratio	Probability
S	29983.141	7	4283.305	0.667	
T	111.038	1	111.038		
ST	1164.347	7	166.335	0.568	
D	685.803	3	228.601		
SD	8439.992	21	401.904	3.449	0.05
TD	1008.616	3	336.205		
STD	2046.728	21	97.463		
TOTAL	43439.656	63			

Key:

Factors	Levels
S - Subjects	1 = U, 2 = 1, 3 = 2, 4 = K, 5 = W, 6 = P, 7 = 0, 8 = T, 9 = J, 10 = X
T - Trials	1 = CM 1, 2 = CM 2
V - Rotation Rate	1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm, 4 = Prerotation baseline, 5 = Postrotation baseline
P - Protocol	1 = MSP; 2 = SSP; 3 = SSP_2; 4 = SSP3, With Head Motions; 5 = SSP4
D - Pharmaceutical	1 = Dramamine, 2 = Scopolamine/Dexedrine, 3 = Placebo, 4 = Phenergan/Ephedrine

Table 35. Newman-Kuels Analysis of LCC Performance

STD MODE/MSP

	Pre-	4 rpm	5 rpm	6 rpm
Post-	NS	NS	**	**

	T 2	T 4	T 1	Warmup
T 3	**	**	**	**
T 2		NS	**	**
T 4			*	**

STD MODE/SSP3 (HM)

	T 2	T 1
T 3	*	*
T 2		NS

CM MODE/MSP

	Pre-	4 rpm	5 rpm	6 rpm
Post-	*	*	*	*

CM MODE/MSP vs SSP

	SSP1	SSP2	SSP4
MSP	*	*	*

NS Not significant
* Significant at the 0.05 level
** Significant at the 0.01 level

Key T = Trial; MSP = Multiple station protocol
SSP = Single station protocol; HM = Head motions

Pharmaceutical Evaluations

These tests used the head motion mode as the basis for comparisons of the effects of the pharmaceuticals on performance. Each of the 11 test subjects performed the DRT test after having received one of the three anti-motion sickness compounds, or placebo on four different test days.

DRT Performance Results

The results of the DRT performance are presented in Tables 36 through 42. The pre- and postrotational test baseline values are presented in Table 36. Comparison of the prerotational test values with the post-test values indicates that learning was a factor during the course of the test program. There were no statistically significant difference with respect to orientation or head motions in the postrotational test baselines, nor in the evaluation of fatigue effects. However, a definite trend toward slower performance was observable between series and among trials. The lack of significant differences indicate that changes in the performance of test sessions were not impacted by a fatigue factor.

Standard Mode

The results for the standard mode are given in Tables 37 and 39. The analyses of performance during the standard mode indicate no differences in performance among the couch orientations or between the 40- and 80-foot (12 and 24 m) radii. Also, no differences were found among the MSP, the subperiods of the SSP performance values. The results did indicate however, that for the MSP there was a significant difference ($P \leq 0.05$) between the post-test baseline and the 6 rpm performance at 40 feet (12 m) and 5 rpm performance at the 80-foot (24 m) station. This difference was not found for the SSP. These results would suggest that 5 rpm at 80 ft (24 m) and 6 rpm at 40 ft (12 m) are within a higher provocative range than the lower rotational rates or shorter radii. Also, the movement along the beam associated with MSP as opposed to SSP was probably very influential in the results. The final significant result was that the second trial was slower than the first ($P \leq 0.05$). This fact may be related to the delayed response of the vestibular system after motion. The motion in this case being associated with moving the couch to a new position between sequences, and therefore, simulating the vestibular system.

Table 36. Baseline Values for DRT Performance

ORIENTATIONS (POST-TEST)

	Pretest	Pro−	45° Pro−	Axial	45° Anti−	Anti−	Total
Mean	19.15[a]	19.31	18.31	18.10	18.34	18.23	18.46
SD	3.03	3.82	2.72	2.19	3.20	2.72	2.93
N	22	22	22	22	22	22	110

HEAD MOTIONS (POST-TEST)

	HX	HO1	HO2	HC1	HC2	T1	T2
Mean	18.49	18.00	17.85	18.06	18.24	17.81	18.39
SD	2.74	3.12	2.39	3.17	3.85	2.84	3.15
N	22	22	22	22	22	55	55

FATIGUE EFFECTS (POST-TEST)

	A_2	A_3	B_2	B_3	T_1	T_2	T_3
Mean	18.35	18.86	18.64	18.77	18.34	18.55	19.73
SD	3.66	2.74	3.06	3.32	3.17	3.13	3.09
N	22	33	22	33	44	44	22

Key:

HX = Warmup; HO = Head motion, with eyes open; HC = Head motion, with eyes closed; T = Trial or repitition

A2 = Two sequences with DRT in Mode A setting;
A3 = Three sequences
B2 = Two sequences with DRT in Mode B setting;
B3 = Three sequences

[a] Values are time in seconds to complete one sequence on DRT.

Table 37. Effect of Rotation Rate and Radius on DRT Performance

MSP-SSP MODE

Station		4 rpm	5 rpm	6 rpm	Pro-	45° Pro	Axial	45° Anti	Anti-	T_1	T_2
ft (m)	Mean	19.41[a]	19.67	20.14	19.76	19.57	19.79	19.51	20.14	19.44	20.08
40 (12)	SD	3.91	4.10	4.05	3.93	4.40	3.76	3.75	4.43	3.91	4.16
	N	100	100	100	60	60	60	60	60	150	150
	Mean	19.42	19.84		19.67	19.95	19.68	19.30	19.53	19.40	19.86
80 (24)	SD	3.95	4.27		4.04	4.46	4.49	3.74	19.53	3.83	4.36
	N	100	100		40	40	40	40	40	100	100

MSP-HM MODE

Station		4 rpm	5 rpm	6 rpm	HX	HO_1	HO_2	HC_1	HC_2	T_1	T_2
ft (m)	Mean	19.41[a]	19.55	19.84	20.3	19.99	19.15	19.30	18.88	19.16	19.98
40 (12)	SD	3.98	3.86	3.83	3.96	4.04	3.73	3.80	3.40	3.75	3.83
	N	100	100	100	60	60	60	60	60	150	150
	Mean	19.13	19.93		19.61	19.64	19.48	19.54	19.48	19.35	19.75
80 (24)	SD	3.59	4.26		4.01	3.48	4.33	4.20	3.87	3.78	4.13
	N	110	110		44	44	44	44	44	110	110

[a] Time in seconds to complete one sequence

Key - HX = warmup; HO = Head motion, eyes open; HC = Head motion, eyes closed, T = Trials

Table 37. Effect of Rotation Rate and Radius on DRT Performance (Cont)

SSP-STD MODE														
Station		4 rpm	5 rpm	6 rpm	Pro-	45 Pro-	Axial	45 Anti-	Anti	P_1	P_2	P_3	P_4
ft (m)	Mean	22.6[a]	21.62	21.91	21.93	22.30	21.59	22.32	22.32	22.16	22.47	21.87	21.51
40 (12)	SD	4.57	3.77	5.79	4.89	5.22	5.01	4.85	4.39	4.69	5.51	4.93	4.21
	N	120	120	120	72	72	72	72	72	90	90	90	90
	Mean	19.61	18.2		18.99	19.55	18.92	18.8	18.22	18.88	19.65	17.87	19.22
80 (24)	SD	4.88	2.73		4.30	3.93	5.16	3.62	2.78	4.04	4.99	2.85	3.77
	N	80	80		32	32	32	32	32	40	40	40	40

SSP-HEAD MOTION MODE															
Station		4 rpm	5 rpm	6 rpm	HX	HO_1	HO_2	HC_1	HC_2	P_1	P_2	P_3	P_4	T_1	T_2
ft (m)	Mean	22.88[a]	20.95	21.68	22.28	22.04	21.59	21.53	21.54	22.15	21.73	22.03	21.48	21.39	22.21
40 (12)	SD	5.43	4.38	5.12	5.17	4.95	4.87	4.99	5.07	4.77	5.17	5.50	4.62	4.80	5.14
	N	120	120	120	72	72	72	72	72	90	90	90	90	180	180
	Mean	19.39	17.97		19.43	18.84	18.72	17.99	18.62	18.41	19.29	18.79	18.37	18.38	19.05
80 (24)	SD	4.60	2.37		5.11	3.89	3.42	2.84	2.96	2.99	4.73	3.65	3.37	3.40	4.01
	N	80	80		32	32	32	32	32	40	40	40	40	80	80

Table 38. Effects of Pharmaceuticals, Head Motion, and Trials DRT Performance at 40 ft (12 m) and 6 rpm

	A	B	C	D	HX	HO_1	HO_2	HC_1	HC_2	T_1	T_2
Mean	19.61[a]	19.67	19.39	19.28	20.24	19.81	18.76	19.53	19.16	19.21	19.74
SD	3.88	4.51	3.71	4.24	4.39	3.96	3.95	3.89	4.18	4.09	4.06
N	90	90	90	90	72	72	72	72	72	180	180

[a]Time in seconds to complete one sequence

Key:

A = Dramamine, B = Scopolamine/Dexedrine, C = Placebo
D = Phenergan/Ephedrine
HX = Warmup; HO = Head motion; eyes open;
HC = Head motion, eyes closed
T = Trial

Table 39. Analysis of Variance of DRT Performance — Standard Mode

40 ft MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	3926.061	9	436.229		
V	195.544	3	65.181	4.600	0.001
SV	383.405	27	14.200		
O	14.352	4	3.588	0.554	- - -
SO	233.032	36	6.473		
VO	84.156	12	7.013	1.561	0.20
SVO	485.006	108	4.491		
T	39.094	1	39.094	9.233	0.025
ST	38.108	9	4.234		
VT	10.231	3	3.410	0.680	- - -
SVT	135.394	27	5.015		
OT	16.499	4	4.125	1.530	- - -
SOT	97.012	36	2.695		
VOT	27.487	12	2.291	0.671	- - -
SVOT	368.214	108	3.409		
TOTAL	6053.566	399			

80 ft MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	3065.523	9	340.614		
V	131.463	2	65.731	5.177	0.025
SV	228.510	18	12.695		
O	11.513	4	2.878	1.849	- - -
SO	56.009	36	1.556		
VO	25.257	8	3.157	0.780	- - -
SVO	291.390	72	4.047		
T	19.846	1	19.846	6.914	0.05
ST	25.832	9	2.870		
VT	2.708	2	1.354	0.603	- - -
SVT	40.372	18	2.243		
OT	26.339	4	6.585	1.797	0.20
SOT	131.860	36	3.663		
VOT	18.274	8	2.284	0.550	- - -
SVOT	298.546	72	4.146		
TOTAL	4373.438	299			

Table 39. Analysis of Variance of DRT Performance — Standard Mode (Cont)

40/80 ft MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	4892.410	9	543.601		
V	10.824	1	10.824	3.741	0.10
SV	26.035	9	2.893		
R	0.504	1	0.504	0.099	- - -
SR	45.765	9	5.085		
VR	0.846	1	0.846	0.294	- - -
SVR	25.844	9	2.872		
O	13.698	4	3.425	1.285	- - -
SO	95.907	36	2.664		
VO	12.649	4	3.162	0.488	- - -
SVO	233.080	36	6.474		
RO	19.790	4	4.948	1.296	- - -
SRO	137.409	36	3.817		
VRO	27.592	4	6.898	1.592	- - -
SVRO	155.930	36	4.331		
T	43.825	1	43.825	6.150	0.05
ST	64.130	9	7.126		
VT	5.522	1	5.522	3.394	0.10
SVT	14.641	9	1.627		
RT	4.368	1	4.368	1.289	- - -
SRT	30.481	9	3.387		
VRT	0.078	1	0.078	0.015	- - -
SVRT	46.276	9	5.142		
OT	16.866	4	4.216	0.868	- - -
SOT	174.828	36	4.856		
VOT	16.790	4	4.198	1.108	- - -
SVOT	136.359	36	3.788		
ROT	34.293	4	8.573	2.110	0.20
SROT	146.250	36	4.063		
VROT	4.216	4	1.054	0.233	- - -
SVROT	162.821	36	4.523		
TOTAL	6599.984	399			

Table 39. Analysis of Variance of DRT Performance – Standard Mode (Cont)

40 ft SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	1424.778	2	712.389		
O	18.781	4	4.695	2.203	0.20
SO	17.050	8	2.131		
V	142.766	3	47.589	1.541	- - -
SV	185.260	6	30.877		
OV	52.524	12	4.377	0.545	- - -
SOV	192.640	24	8.027		
T	12.519	1	12.519	3.505	- - -
ST	7.142	2	3.571		
OT	32.557	4	8.139	0.939	- - -
SOT	69.310	8	8.664		
VT	1.313	3	0.438	0.069	- - -
SVT	37.951	6	6.325		
OVT	105.341	12	8.778	1.055	- - -
SOVT	199.580	24	8.316		
TOTAL	2499.511	119			

80 ft SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	505.470	1	505.470		
O	45.526	4	11.381	3.449	0.20
SO	13.199	4	3.300		
V	49.263	2	24.632	1.068	- - -
SV	46.108	2	23.054		
OV	78.075	8	9.759	2.204	0.20
SOV	35.419	8	4.427		
T	0.185	1	0.185	0.082	- - -
ST	2.247	1	2.247		
OT	2.631	4	0.658	0.520	- - -
SOT	5.055	4	1.264		
VT	1.725	2	0.863	0.202	- - -
SVT	8.520	2	4.260		
OVT	24.017	8	3.002	0.705	- - -
SOVT	34.040	8	4.255		
TOTAL	851.476	59			

Table 39. Analysis of Variance of DRT Performance — Standard Mode (Cont)

40 ft MSP/SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	6429.020	1	6429.020		
O	30.198	4	7.549	0.557	- - -
SO	54.210	4	13.553		
V	47.594	2	23.797	0.692	- - -
SV	68.726	2	34.363		
OV	36.970	8	4.621	0.487	- - -
SOV	75.912	8	9.489		
P	40.544	4	10.136	1.227	- - -
SP	33.038	4	8.260		
OP	121.930	16	7.621	1.111	- - -
SOP	109.662	16	6.854		
VP	140.617	8	17.577	1.073	- - -
SVP	130.968	8	16.371		
OVP	289.884	32	9.059	1.117	- - -
SOVP	259.397	32	8.106		
T	101.874	1	101.874	4.587	- - -
ST	22.206	1	22.206		
OT	21.218	4	5.304	0.633	- - -
SOT	33.504	4	8.376		
VT	4.043	2	2.021	1.043	- - -
SVT	3.872	2	1.936		
OVT	79.537	8	9.942	0.609	- - -
SOVT	130.394	8	16.299		
PT	9.389	4	2.347	0.197	- - -
SPT	47.640	4	11.910		
OPT	122.718	16	7.670	0.615	- - -
SOPT	199.305	16	12.457		
VPT	76.842	8	9.605	0.794	- - -
SVPT	96.746	8	12.093		
OVPT	208.424	32	6.513	1.367	- - -
SOVPT	152.357	32	4.761		
TOTAL	9178.660	299			

Table 39. Analysis of Variance of DRT Performance — Standard Mode (Cont)

80 ft MSP/SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	1693.094	1	1693.094		
O	22.845	4	5.711	0.884	- - -
SO	25.827	4	6.457		
V	50.693	1	50.693	0.762	- - -
SV	66.459	1	66.459		
OV	51.918	4	12.979	3.595	0.20
SOV	14.438	4	3.610		
P	81.084	4	20.271	1.632	- - -
SP	49.658	4	12.414		
OP	69.852	16	4.366	1.297	- - -
SOP	53.830	16	3.364		
VP	99.710	4	24.928	1.036	- - -
SVP	96.239	4	24.060		
OVP	102.115	16	6.382	1.181	- - -
SOVP	86.425	16	5.402		
T	0.649	1	0.649	50.050	0.10
ST	0.013	1	0.013		
OT	23.301	4	5.825	0.989	- - -
SOT	23.558	4	5.889		
VT	1.547	1	1.547	0.298	- - -
SVT	5.181	1	5.181		
OVT	14.346	4	3.586	1.470	- - -
SOVT	9.759	4	2.440		
PT	23.443	4	5.861	7.102	0.05
SPT	3.301	4	0.825		
OPT	54.701	16	3.419	0.805	- - -
SOPT	67.896	16	4.244		
VPT	5.644	4	1.411	0.604	- - -
SVPT	9.334	4	2.334		
OVPT	64.214	16	4.013	1.133	- - -
SOVPT	56.647	16	3.540		
TOTAL	2927.718	199			

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Table 39. Analysis of Variance of DRT Performance — Standard Mode (Cont)

Key		
Factors		Levels
S —	Test subjects	1 = U, 2 = 1, 3 = K, 4 = W, 5 = P, 6 = M, 7 = O, 8 = T, 9 = J, 10 = X
V —	Rotation rates	1 = 4 rpm, 2 = 5 rpm, 3 = rpm, 4 = Post-test baseline
O —	Orientations	1 = Pro-spin, 2 = 45° Pro-spin, 3 = Axial, 4 = 45° Anti-spin, 5 = Anti-spin
T —	Trials	1 = First, 2 = Second
R —	Radius	1 = 40 ft (12m), 2 = 80 ft (24m)
P —	Protocols	1 = MSP, 2 = SSP1, 3 = SSP2, 4 = SSP3, 5 = SSP4

Table 40. Analysis of Variance of DRT Performance — Head Motion Mode

40 ft MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	3774.554	9	419.395		
H	66.940	4	16.735	4.293	0.01
SH	140.330	36	3.898		
V	186.909	3	62.303	9.280	0.001
SV	181.259	27	6.713		
HV	45.941	12	3.828	0.934	- - -
SHV	442.580	108	4.098		
T	52.765	1	52.765	10.489	0.025
ST	45.273	9	5.030		
HT	19.745	4	4.936	2.137	0.1
SHT	83.147	36	2.310		
VT	14.148	3	4.716	1.449	- - -
SVT	87.873	27	3.255		
HVT	22.266	12	1.855	0.651	- - -
SHVT	307.392	108	2.846		
TOTAL	5471.090	399			

80 ft MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	2987.192	10	298.719		
H	3.515	4	0.879	1.89	- - -
SH	185.825	40	4.646		
V	186.755	2	93.377	12.357	0.001
SV	151.131	20	7.557		
HV	31.064	8	3.883	1.020	- - -
SHV	304.280	80	3.803		
T	17.109	1	17.109	2.738	0.2
ST	62.474	10	6.247		
HT	22.955	4	5.739	2.381	0.1
SHT	96.400	40	2.410		
VT	3.018	2	1.509	0.283	- - -
SVT	106.378	20	5.319		
HVT	94.155	8	11.769	3.093	0.01
SHVT	304.350	80	3.804		
TOTAL	4556.594	329			

Table 40. Analysis of Variance of DRT Performance – Head Motion Mode (Cont)

40/80 ft MSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	4518.156	9	502.017		
H	29.253	4	7.313	1.132	- - -
SH	232.475	36	6.458		
V	24.503	1	24.503	1.722	- - -
SV	128.029	9	14.225		
HV	10.337	4	2.584	0.691	- - -
SHV	134.576	36	3.738		
R	0.044	1	0.044	0.010	- - -
SR	36.957	9	4.106		
HR	20.967	4	5.242	0.996	- - -
SHR	189.407	36	5.261		
VR	12.603	1	12.603	4.886	0.1
SVR	23.216	9	2.580		
HVR	19.303	4	4.826	1.116	- - -
SHVR	155.635	36	4.323		
T	40.960	1	40.960	7.338	0.025
ST	50.235	9	5.582		
HT	23.307	4	5.827	2.332	- - -
SHT	89.949	36	2.499		
VT	11.696	1	11.696	2.359	0.2
SVT	44.616	9	4.957		
HVT	17.496	4	4.375	1.273	- - -
SHVT	123.602	36	3.433		
RT	0.774	1	0.774	0.183	- - -
SRT	37.927	9	4.214		
HRT	41.002	4	10.250	3.705	0.025
SHRT	99.588	36	2.766		
VRT	1.254	1	1.254	0.225	- - -
SRVT	50.111	9	5.568		
HVRT	12.603	4	3.151	1.189	- - -
SHVRT	95.371	36	2.649		
TOTAL	6275.906	399			

Table 40. Analysis of Variance of DRT Performance — Head Motion Mode (Cont)

40 ft SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	1505.391	2	752.696		
H	6.291	4	1.573	0.191	- - -
SH	65.535	8	8.192		
V	200.700	3	66.900	7.316	0.025
SV	54.863	6	9.144		
HV	89.367	12	7.447	1.859	0.1
SHV	96.123	24	4.005		
T	37.141	1	37.141	2.542	- - -
ST	29.218	2	14.609		
HT	19.535	4	4.884	0.354	- - -
SHT	110.164	8	13.771		
VT	1.978	3	0.659	0.142	- - -
SVT	27.773	6	4.629		
HVT	81.135	12	6.761	1.061	- - -
SHVT	152.847	24	6.369		
TOTAL	2478.058	119			

40/80 ft SSP

Source of Variance	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	280.930	1	280.930		
H	8.603	4	2.151	1.560	- - -
SH	5.515	4	1.379		
V	19.180	2	9.590	5.865	0.2
SV	3.270	2	1.635		
HV	43.109	8	5.389	4.619	0.024
SHV	9.331	8	1.166		
T	11.085	1	11.085	14.598	0.2
ST	0.759	1	0.759		
HT	11.855	4	2.964	0.901	- - -
SHT	13.152	4	3.288		
VT	1.650	2	0.825	42.036	0.025
SVT	0.039	2	0.020		
HVT	19.191	8	2.399	0.798	- - -
SHVT	24.027	8	3.003		
TOTAL	451.696	59			

Table 40. Analysis of Variance of DRT Performance — Head Motion Mode (Cont)

40 ft MSP/SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	7315.898	2	3657.949		
H	53.076	4	13.269	2.683	0.2
SH	39.551	8	4.944		
V	154.793	2	77.397	4.400	0.1
SV	70.352	4	17.588		
HV	77.694	8	9.712	1.824	0.2
SHV	85.159	16	5.322		
T	65.856	1	65.856	12.396	0.1
ST	10.625	2	5.313		
HT	15.508	4	3.877	0.837	- - -
SHT	37.028	8	4.628		
VT	5.289	2	2.645	0.923	- - -
SVT	11.452	4	2.863		
HVT	54.452	8	6.806	1.331	- - -
SHVT	81.801	16	5.112		
P	25.642	4	6.410	0.387	- - -
SP	132.456	8	16.557		
HP	88.904	16	5.557	0.709	- - -
SHP	250.623	32	7.832		
VP	85.094	8	10.637	1.410	- - -
SVP	120.677	16	7.542		
HVP	211.085	32	6.596	1.179	- - -
SHVP	357.940	64	5.593		
TP	18.927	4	4.732	0.790	- - -
STP	47.911	8	5.897		
HTP	61.923	16	3.870	0.692	- - -
SHTP	178.960	32	5.592		
VTP	31.471	8	3.934	0.875	- - -
SVTP	71.869	16	4.492		
HVTP	214.876	32	6.715	1.108	- - -
SHVTP	387.736	64	6.058		
TOTAL	10364.578	499			

Table 40. Analysis of Variance of DRT Performance — Head Motion Mode (Cont)

80 ft MSP/SSP

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	1625.067	1	1625.067		
H	24.885	4	6.221	0.710	- - -
SH	35.032	4	8.758		
V	39.694	1	39.694	0.856	- - -
SV	46.368	1	46.368		
HV	30.923	4	7.730	2.52	0.2
SHV	12.226	4	3.056		
T	13.572	1	13.572		
ST	9.901	1	9.901		
HT	15.822	4	3.956		
SHT	15.734	4	3.934		
VT	0.638	1	0.638	260.59	0.05
SVT	0.002	1	0.002		
HVT	7.156	4	1.789		
SHVT	18.581	4	4.645		
P	81.295	4	20.324	3.79	0.2
SP	21.402	4	5.350		
HP	116.988	16	7.311		
SHP	97.287	16	6.080		
VP	66.984	4	16.746		
SVP	153.016	4	38.254		
HVP	45.170	16	2.823		
SHVP	49.276	16	3.080		
TP	20.802	4	5.200	2.31	- - -
STP	8.987	4	2.247		
HTP	87.515	16	5.470	1.50	- - -
SHTP	58.293	16	3.643		
VTP	8.840	4	2.210	2.89	0.2
SVTP	3.053	4	0.763		
HVTP	50.041	16	3.128		
SHVTP	46.804	16	2.925		
TOTAL	2811.352	199			

Table 40. Analysis of Variance of DRT Performance — Head Motion Mode (Cont)

Key:	
Factors	**Levels**
S — Test subjects	1 = U, 2 = 1, 3 = 2, 4 = K, 5 = W, 6 = P, 7 = M, 8 = 0, 9 = T, 10 = J, 11 = X
H — Head movements	1 = HX, Warmup; 2 = HO1, Eyes open; 3 = HO2, Eyes open; 4 = HC1, Eyes closed; 5 = HC2, Eyes closed
V — Rotation rates	1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm, 4 = Post-Test baseline
T — Trials	1 = First, 2 = Second
P — Protocols	1 = MSP, 2 = SSP1, 3 = SSP2, 4 = SSP3, 5 = SSP4
R — Radius	1 = 40 ft (12m), 2 = 80 ft (24m)

Table 41. Analysis of Variance of DRT Performance — Pharmaceutical Evaluations

Time

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	4115.26953	8	514.40869		
D	7.87881	3	2.62627	0.221	- - -
SD	284.17603	24	11.84067		
H	94.19371	4	23.54842	10.584	0.001
SH	71.19623	32	2.22488		
DH	52.26100	12	4.35508	0.817	- - -
SDH	511.63354	96	5.32952		
T	24.80624	1	24.80624	3.300	0.20
ST	60.13187	8	7.51648		
DT	1.88077	3	0.62692	0.102	- - -
SDT	147.15681	24	6.13153		
HT	22.39561	4	5.59890	2.018	0.20
SHT	88.77141	32	2.77411		
DHT	66.64126	12	5.55355	1.234	- - -
SDHT	431.89111	96	4.49887		
TOTAL	5980.26172	359			

Table 41. Analysis of Variance of DRT Performance — Pharmaceutical Evaluations (Cont)

Errors

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	881.93872	8	110.24234		
D	54.13333	3	18.04443	3.164	0.05
SD	136.61665	24	5.69236		
H	19.76111	4	4.94028	1.455	- - -
SH	108.58888	32	3.39340		
DH	34.72777	12	2.89398	0.705	- - -
SDH	393.52002	96	4.09917		
T	2.84444	1	2.84444	0.560	- - -
ST	40.60555	8	5.07569		
DT	3.95555	3	1.31852	0.265	- - -
SDT	119.19444	24	4.96643		
HT	17.23888	4	4.30972	1.261	- - -
SHT	109.31110	32	3.41597		
DHT	72.18332	12	6.01528	1.601	0.10
SDHT	360.66113	96	3.75689		
TOTAL	2355.27930	359			

Time to First Response

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
S	161.89685	8	20.23711		
D	0.17141	3	0.05714	0.062	- - -
SD	21.84224	24	0.91009		
H	4.39570	4	1.09892	2.053	0.20
SH	17.12515	32	0.53516		
DH	9.88758	12	0.82396	1.231	- - -
SDH	64.22617	96	0.66902		
T	0.36735	1	0.36735	0.401	- - -
ST	7.31788	8	0.91473		
DT	0.75274	3	0.25091	0.466	- - -
SDT	12.91493	24	0.53812		
HT	0.29083	4	0.07271	0.162	- - -
SHT	14.33006	32	0.44781		
DHT	8.24619	12	0.68718	0.947	- - -
SDHT	69.60330	96	0.72503		
TOTAL	393.36743	359			

Table 41. Analysis of Variance of DRT Performance — Pharmaceutical Evaluations (Cont)

Key:

Factors	Levels
S — Test subject	1 = U, 2 = 1, 3 = K, 4 = W, 5 = P, 6 = M, 7 = O, 8 = J, 9 = X
D — Pharmaceuticals	1 = Dramamine, 2 = Phenergan/ Ephedrine, 3 = Placebo, 4 = Scopolamine/ Dexedrine
H — Head movements	1 = HX, Warmup; 2 = HO1, Eyex open; 3 = HO2, Eyes open, 4 = HC1, Eyes closed; 5 = HC2, Eyes closed
T — Trials	1 = First, 2 = Second

Table 42. Newman-Kuels Analysis of 40 ft (12m) DRT Performance With Head Motions

MSP

	HO2	HC1	HC2
HX	**	**	**
HO1	*	*	*

	4 rpm	5 rpm	6 rpm
Post-Test	**	**	**

SSP

	4 rpm	5 rpm	6 rpm
Post-Test	**	**	**

PHARMACEUTICAL EVALUATIONS

	HO2	HC1	HC2
HX	**	*	**
HO1	**	NS	*
HC1	**	—	NS

NS Not significant
* Significant at the 0.05 level
** Significant at the 0.01 level

Table 42. Newman-Kuels Analysis of 40 ft (12m) DRT Performance With Head Motions (Cont)

Key:
HX = Warmup Trial, HO = Head Motion, eyes open, HC-
HC = Head Motion, eyes closed
MSP = Multiple Station Protocol, SSP = Single Station Protocol

Head Motion Mode

The results of these evaluations are presented in Tables 37, 40, and 42. As found in the STD mode, DRT performance was degraded by rotation, except that the combination of head motions and rotation resulted in significantly slower performance at rates during both MSP and SSP at the 40-foot (12 m) station ($P \geq 0.01$). However, at the 80-foot (24 m) station where 4 and 5 rpm were evaluated, only the 5 rpm performance was significantly slower than baseline performance ($P \geq 0.05$). The effect of head motions revealed that the first set of motions was not significantly different from the warmup scores. It was found that during MSP performance at the 40-foot (12 m) station that HO2, HC1, and HC2 were much better than the warmup (HX) trials ($P \geq 0.01$) and significantly better than HO1 ($P \geq 0.05$). This difference was not obtained during SSP performance. While not statistically significant, the first trial was generally better than the second with all conditions. The test subjects were exposed to 4, 5, and 6 rpm while performing this task except at the 80-foot (24 m) station where, at 6 rpm, the test station couch was too difficult to enter and leave, due to the force of the resultant vector (≈ 1.4 g). Each test subject performed the task under the MSP and SSP. Each SSP period was identical to the MSP, except that the test subject remained at the one station for the total session. The protocol for the standard mode allowed comparison among the rotation rates and baselines, between MSP and SSP, between 40 and 80 feet radii, and among the five orientations.

Pharmaceutical Evaluations

These tests were all performed at the 6 rpm rotational rate, and therefore, only at the 40-foot (12 m) position. The results of these evaluations are presented in Tables 38, 41 and 42. The results relative to head motions, with anti-motion sickness pharmaceuticals are quite similar to the results without pharmaceuticals except that HC1 performance was found to be significantly slower than HO2 ($P \geq 0.01$). The results among the pharmaceuticals and placebo were found to be very similar, indicating no effect on the performance of this task. However, in analysing the performance for "errors" and "time to first response" the Scopolamine/Dexedrine combination was found to result in significantly more "errors" ($P \geq 0.05$) than the other pharmaceuticals and placebo. No other significant findings were evident.

LOCOMOTION EVALUATIONS

A considerable portion of the present study has been allocated to evaluations of the effects of orientation, direction of travel, and rotational rate on locomotion capabilities. These items will be presented in the following order: elevator, ladder, walking, cargo transport, and cargo handling. It has been postulated that radial motion would result in seriously adverse psychophysiological effects and severe locomotion deterioration. In addition, it has been predicted that activity in the vicinity of or across the axis of rotation would result in the onset of illusions and mental confusion, due to changes in both magnitude and direction of the artificial g force and the large differential ratio of artificial g and Coriolis forces. "Radial transport across the axis of rotation or even stationary activity at the rotating axis probably could not be tolerated unless the 'hub' of the vehicle were nonrotating, with provisions made for transfer from moving 'spoke' to nonrotating hub at some minimum radius, as from 6 to 10 feet" (Reference 18). This and other background information relative to locomotion was used in the experimental design and development of the present program for evaluation and/or verification (References 8, 10, 19).

Elevator

Passive radial transfer was evaluated by means of an elevator cart, in which the test subjects were transported from a radius of approximately five feet (1.5 m) to a 65-foot (20 m) position. The individuals were exposed to two ascent-descent cycles while facing pro-spin, anti-spin, and axial (facing up) at linear rates of 4, 6, 8 ft/s (1.2, 1.8, 2.4 m/s) at all three rotational rates. Subjective comments, and observation of test subject response were used in an effort to quantify the results.

Elevator Results

Radial transfer using the elevator (cart) resulted in very positive statements by the test subjects relative to the use of this mode of radial transfer as a potential for use between levels in a space station/base type complex. The test subjects reported a significant impression of curved rather than linear transfer at all angular rotation rates and linear elevator rates of 4 to 8 feet per second. The intensity of this illusion appeared to be a function of both the rotational and linear velocities coupled with subject orientation, i.e., the higher the velocities the more intense the illusion with maximum intensity being experienced in the face-down position, followed closely by the face-up position. There appeared to be a significant reduction in intensity of the illusion while facing in both the pro and anti-spin orientations, with no significant difference being noted between the two. The subjective impression of the differing magnitudes relative to the curvilinear phenomena, was believed to be related principally to the initial acceleration of the elevator, with its continuance being dependent upon the intensity of the resultant Coriolis forces. No problems of excess stimulation resulting in malaise was reported for this experimental task; rather, the test subjects reported this test to be quite pleasant, even at the maximum rates employed. It was found that the magnitude of the Coriolis forces generated near the hub (< 0.1 g) were of sufficient magnitude to produce lateral body movement at the higher rotational rates. This fact emphasizes the need for hand holds and possibly restraints at high angular or linear rates on a rotating space vehicle.

Ladder Climbing

Radial transfer, as affected by rotational rate, body orientation, and ladder rung configuration, was evaluated with the test subjects suspended in a sling system between two ladders (see Figure 6). The test subjects worked in two-man teams for this task, with one man climbing and his alternate assisting him into and out of the sling, making observations, and timing the traversals. The test subjects descended and ascended three times, each of the two radially oriented ladders, alternately using the pro-spin or anti-spin ladder. During the initial phase of the program, the standard ladders with constant 12-inch rung spacing were utilized, with all test subjects being exposed to these two ladders at all rates. During the second phase, the test subjects performed the task with ladders 2 and 3, having varied rung spacings, oriented pro-spin and anti-spin, respectively. In the final phase, the orientation of these ladders was reversed. The task was self-paced, with the objective of establishing a comfortable and safe rate of climbing, under the various test conditions.

Ladder Climbing Results

The test subjects reported no excessively adverse effects of radial transfer due to the Coriolis and cross-coupled angular accelerations. This same response was observed in the case of the elevator transfer, but was not completely conclusive due to the subject's reduced proprioceptor input while lying in the cart. The relative freedom of motion in the sling system tends to confirm the observation.

The mean rate of ladder climbing is about 2.5 ft/s (.76 m/s), with the rate being approximately 2.4 ft/s (.73 m/s) at the 6 rpm rate and 2.6 ft/s (.79 m/s) at 4 rpm. A more detailed treatment of these data is presented in Table 43. Statistical treatment of the data is presented in Tables 44 and 45. There has been no attempt to correct the values for training effects, although these were quite apparent, especially in the case of ladder 1.

Table 43. Rate of Ladder Climbing Relative to Rotational Rate, Orientation, and Ladder Configuration

rpm	Ladder	1		2		3		Rate Means
	Orientation	Ascent	Descent	Ascent	Descent	Ascent	Descent	
4	Pro-spin	2.0(.61)[a]	2.2(.67)	2.8(85)	2.9(.88)	3.1(.94)	4.1(1.25)	
	Anti-spin	2.0(.61)	2.0(.61)	3.4(1.04)	3.0(.91)	2.6(.79)	2.3(.70)	2.6(.79)
5	Pro-spin	2.0(.61)	2.3(.70)	2.7(.82)	2.4(.73)	3.0(.91)	3.3(1.01)	
	Anti-spin	1.9(.58)	2.0(.61)	3.4(1.04)	3.0(.91)	2.4(.73)	2.2(.67)	2.5(.76)
6		2.3(.70)	2.0(.61)	2.7(.82)	2.3(.70)	2.9(.88)	2.5(.76)	
	Anti-spin	2.2(.67)	1.9(.58)	2.9(.88)	2.6(.79)	2.2(.67)	2.1(.64)	2.4(.73)

Means Ascent 2.5(.76)
Descent 2.6(.79)

[a] ft/s (m/s)

Table 44. Analysis of Variance for Ladder Climbing

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
L	3021.96	5	604.39	25.45	.001**
V	462.95	2	231.48	9.75	.001**
D	157.78	1	157.78	6.64	.01**
LV	200.07	10	20.01	.842	----
LD	69.72	5	13.94	.586	----
VD	76.2	2	38.1	1.604	----
LVD	165.56	10	16.56	.697	----
Within cell	6744.	284	23.75		

Key -

Factors	Levels
L - Ladders	1 = Ladder 1, Pro-spin; 2 = Ladder 1, Anti-spin; 3 = Ladder 2, Pro-spin; 4 = Ladder 2, Anti-spin; 5 = Ladder 3, Pro-spin; 6 = Ladder 3, Anti-spin.
V - Rotation rate	1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm
D - Direction	1 = Ascent, 2 = Descent

3

Table 45. Newman-Kuels Analysis of Ladder Climbing Performance

CONFIGURATIONS				
	L3	L4	L5	L6
L1[a]	4.54 NS[b]	6.09*	6.30*	2.40 NS
L2	6.65*	8.20*	8.41*	4.51 NS

CONFIGURATION/ROTATIONAL RATES - DESCENT					
		L3	L4	L5	L6
4 rpm	L1[a]	7.72*[b]	6.20*	9.70**	3.87 NS
	L2	8.86*	7.34*	10.84**	5.01 NS
5 rpm	L1	2.33 NS	4.88 NS	6.34 NS	.69 NS
	L2	5.33 NS	7.88*	9.34 **	3.69 NS
6 rpm	L1	3.80 NS	5.61 NS	5.29 NS	1.24 NS
	L2	4.01 NS	6.42*	6.10 NS	2.05 NS

CONFIGURATION/ROTATIONAL RATES - ASCENT					
		L3	L4	L5	L6
4 rpm	L1[a]	3.37 NS[b]	4.51 NS	2.95 NS	3.26 NS
	L2	9.02*	10.16**	8.60*	8.91*
5 rpm	L1	6.99*	10.24**	9.20**	5.14*
	L2	7.49*	10.74**	9.70**	5.64*
6 rpm	L1	3.06 NS	5.12 NS	4.36 NS	.23
	L2	4.60 NS	6.66*	5.90*	1.77 NS

[a]See Table 44 for ladder/configuration key
[b]Values are differences in seconds for one ladder traversal
*Significant at the 0.05 level
**Significant at the 0.01 level
NS Not significant

However, this effect should be reduced significantly by the number of trials and test subjects, particularly as concerns rate and ladder configuration (see Table 44). Generally, ascent is faster than decent, with an exception observed in the case of ladder 2 at the 4 rpm rate. The test subjects exhibited a tendency to want to slide, i.e., hold the side rails of the ladder and ignore the rungs, both in ascent and descent at the 4 and 5 rpm rates. The g levels (>.8 g) and Coriolis forces made it both difficult and dangerous to slide at the 6 rpm rate. The overall performance was significantly better with ladder 2 (12 to 20 in. or 30 to 51 cm rung spacing), with the best performance in the anti-spin orientation on this ladder (condition L4). Ladder 3 (9 to 18 in. or 22.9 to 45.7 cm rung spacing), on the other hand, was best in the pro-spin orientation (condition L5). As has been noted, the apparently poorer performance on ladder 1 may be more related to the error of training effects than on efficiency of the ladder configuration. Nevertheless, the subjective preferences for the ladders agreed, in general, with the objective data. Reference to Table 45 reveals that the L4 and L5 configurations were significantly better than L1, while L3, L4, and L5 were significantly superior to L2 ($P \leq 0.05$). The same relationship is seen in comparison of ladder configurations and rotational rates, with performance on the L5 configuration being highly significant during descent at 4 and 5 rpm, and both L4 and L5 being highly significant ($P \leq 0.01$) relative to better performance at the 4 and 5 rpm rate.

Tangential Locomotion Evaluations

The predicted responses of man to Coriolis forces, cross-coupled angular accelerations, gravity gradients, and total gravity forces, have served as the basis for predicting various parameters as the ideal or physiological limits for tangential locomotion in the rotating environment. The proposed upper limit has been predicted to be at 1.0 to 1.5 g (Reference 18 and 19). Argument against a higher than 1 g level has been based on the fatiguing effect of the additional effective body and cargo weight. Further, as a design consideration, it has been proposed that the rotational rate and/or effective radius be reduced to a level which would prevent an individual from experiencing a force greater than 1.0 g when walking tangentially in the direction of rotation at a rate of 3 to 4 ft/s (.91 to 1.2 m/s) (Reference 19). The lower design limit has been set at 0.1 to 0.2 g, due to potential traction problems. The actual radius-rotational rate has been established at a higher level due to the reduction in effective g when walking tangentially in the anti-spin direction. Other limits which have been proposed included a head to foot ratio of less than .15, i.e., the relationship of centripetal forces experienced at the level of the head versus the forces experienced at the foot level. A degree of discomfort due to leg heaviness has been reported for tangential walking at a 20 ft (6 m) radius when the .15 ratio has been exceeded. On the basis of similar reasoning, the ratio of artificial g to Coriolis force has been recommended to be less than .50, to reduce the possibility of excessive vestibular stimuli (References 10, 18, 19). These recommended limits would establish a maximum tangential locomotion rate at four ft/s (1.2 m/s) and a minimum radius of 40 feet (12 m). The recommended performance limits and experimental points evaluated in this program are presented in Figure 13. The upper and lower curves represent 1.0 and 0.1 g, respectively, in a static situation. The inner curves represent the same g forces when an individual is walking tangentially at 3 ft/s (.9 m/s) in the pro-spin and anti-spin direction, respectively. The open symbols represent rotational rates and radii, evaluated in the previous study (Reference 8) and in the present program. The broken line represents the actual 0.1 g level developed during self-paced tangential locomotion during these walking evaluations.

Tangential locomotion was evaluated to determine the impact of different levels of artificial g on walking rate, starting-stopping, and general body control. These parameters were evaluated while the test subject was suspended in a horizontal orientation by means of a sling system, designed to reduce the impact of the normal g vector. This sling aligned the test subject logitudinally within the artificial g field. The lower leg support was not utilized for walking by the test subjects at the 70 ft (21 m) radius at 6 rpm, in that the centripetal force was adequate to make walking easy without it. This configuration resulted in approximately 3 ft (.9 m) of additional walking surface being available to the test subject.

The experimental factors evaluated included the rotation rates, radii of the walking surface, direction of travel, with flat floors at the 70 ft (21 m), and both flat and curved floors at the 30 and 50 ft (9 and 15 m) radii. The evaluations were performed by two-man test subject teams. The test procedures required the test subject to traverse the 20 ft (6 m) length of the room, at a comfortable pace, maintaining body and posture control, coming to a halt before contacting the opposite wall. Each subject performed a total of four trials in each direction. During the first two trials some experimentation was permitted; however, during the second set of trials, the tasks were to be performed in the best possible manner. These latter two trials were photographed for subsequent analysis. In addition, all four trials were timed between starting and stopping, and subjective comments were obtained through subject debriefings, quentionnaires, and comparison charts.

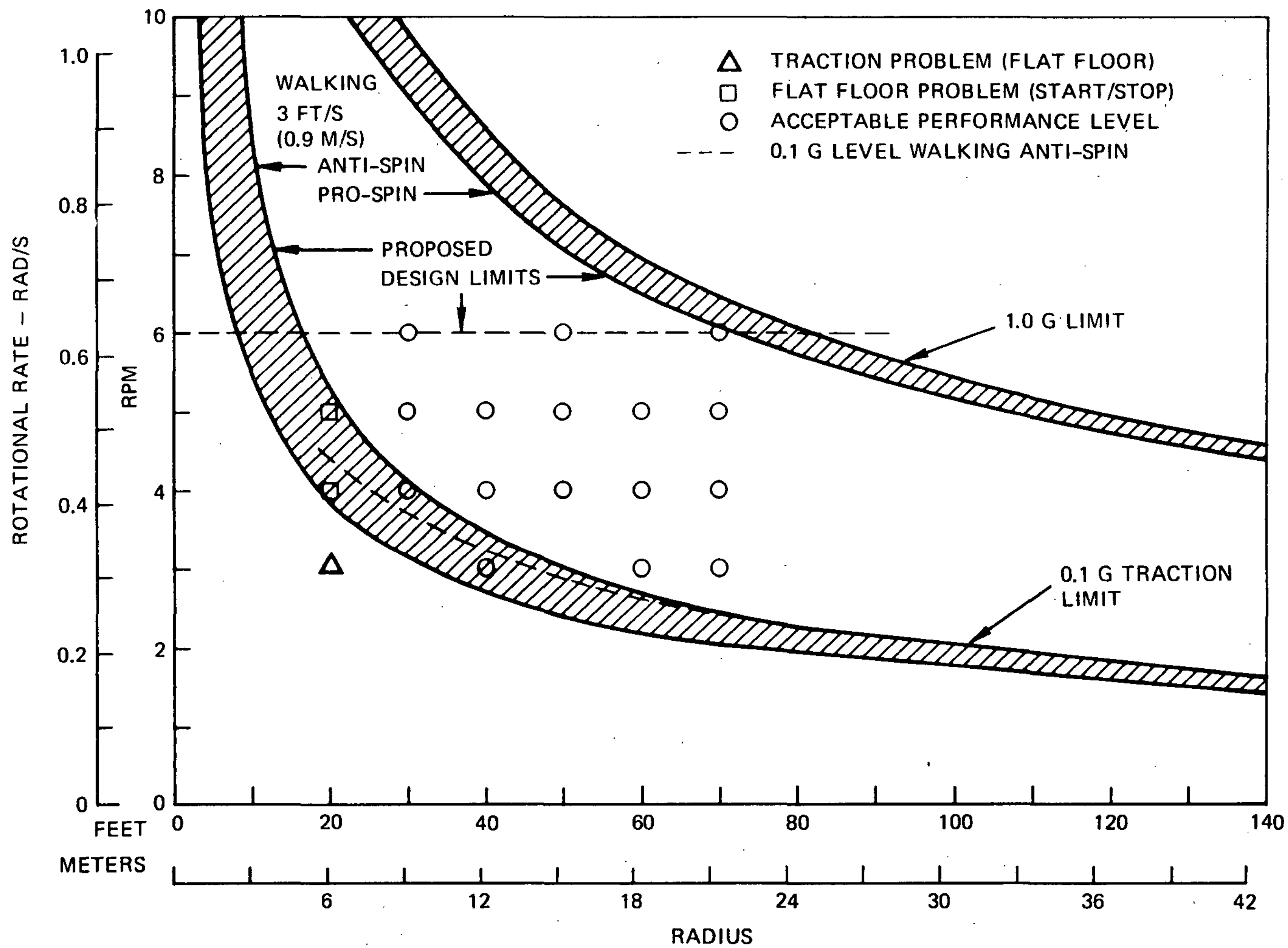

Figure 13. Predicted Performance Limits and Performance Evaluation

Walking Results

The results of the present evaluations have been combined with the results of the first study (Reference 8), to provide data at 3, 4, 5, and 6 rpm as well as radii of 20(6), 40(12), 50(15), 60(18), and 70(21) ft (m). The data were converted into relative g levels and plotted on Figure 14. The walking rates for the present study are presented in Table 46. In that the walking room was located at the 70-ft (21 m) radius for the first series of tests, the data were badly skewed at the 70-ft (21 m) station due to test subject timidity and learning. For this reason, the data for this station were weighted on the basis of the 4 and 5 rpm performance values of the first study (Reference 8), for presentation in Figure 14 and Table 46. Statistical treatment of the raw data from this study is presented in Tables 47 through 49.

It may be observed with reference to Figure 14 that the walking rate is significantly reduced at the lower g levels. The walking rate varied between 1.0 and 3.5 ft/s (.3-1.1 m/s) normally, with experimental rates to five ft/s (1.5 m/s). It is of interest to note that the greatest performance problem below approximately 0.3 g is related to starting and stopping. It should be pointed out that these two factors are included in the time for a traversal, and that the numerical values do not represent instantaneous walking rates. It was found that the 50-ft (15 m) radius at 6 rpm provided the fastest performance time in this study, and was significantly better than performance at the 30-ft (9 m) station ($P \leq 0.01$). Subjectively, a walking condition between 0.4 and 0.6 g was most comfortable, with 4 rpm providing the least stressful rotational rate. While the data for this study indicate a much slower rate of performance at the 70-ft (21 m) position, no significance may be assigned to the statistical analysis due to the extremely large learning error for this test point.

Statistical analyses of floor configurations revealed no difference in the flat floors as contrasted to the curved floors at the 30-ft (9 m) radius (Table 49). However, the subjects felt that performance was better and more comfortable on the curved floors at the shorter radius. There is no statistical difference between flat and curved floors at the 50-ft (15 m) position, but the flat floor was subjectively better at this location. The mean performance time for the 50-ft (15 m) radius was faster than the others in the unweighted data, and comparable to the 70-ft (21 m) in the weighted values.

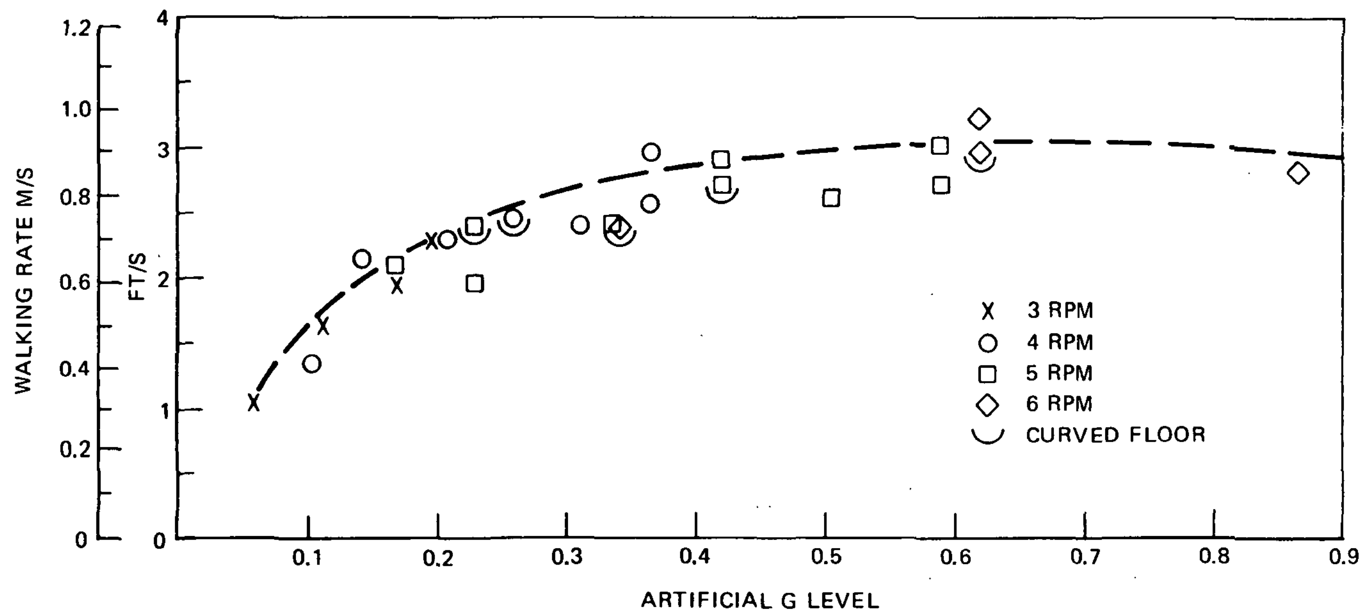

Figure 14. Variations in Walking Rate Relative to Rotation Rate, Floor Configuration, and Artificial g Level

Table 46. Tangential Walking Rate as a Function of Rotational Rate, Radius, and Floor Configuration

Rate - rpm		4		5		6	
Orientation		Pro-Spin	Anti-Spin	Pro-Spin	Anti-Spin	Pro-Spin	Anti-Spin
Configuration							
30 ft (9m)	Flat	2.3(.70)[a]	2.0(.61)	2.1(.64)	1.8(.55)	2.5(.76)	2.2(.67)
	Curved	2.3(.70)	2.0(.61)	2.5(.76)	2.3(.70)	2.5(.76)	2.4(.73)
50 ft (15m)	Flat	2.5(.76)	2.4(.73)	2.9(.88)	2.9(.88)	3.2(.97)	3.2(.97)
	Curved	2.5(.76)	2.4(.73)	2.6(.79)	2.8(.85)	3.1(.94)	2.8(.85)
70 ft (21m)	Flat[b]	2.5(.76)	2.5(.76)	2.8(.85)	2.8(.85)	3.5(1.07)	3.1(.94)

[a] Values in ft/s (m/s)

[b] These values weighted with results of 4 and 5 rpm performance of earlier study (Reference 8) to reduce the impact of learning error.

Table 47. Analysis of Variance for Tangential Walking Performance

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
C	174.38	4	43.60	18.55	0.001
V	29.31	2	14.60	6.24	0.005
D	4.93	1	4.93	2.10	0.2
CV	126.11	8	15.76	6.71	0.001
CD	10.10	4	2.53	1.08	- - -
VD	1.40	2	0.7	0.30	- - -
CVD	0.40	8	0.05	0.02	- - -
MS W/in cell	522.48	222	2.35		

Key - Factors	Levels
C - Conditions	1 = 30 ft, flat floors; 2 = 30 ft, curved floors; 3 = 50 ft, flat floors; 4 = 50 ft, curved floors; 5 = 70 ft, flat floors.
V - Rotation rate	1 = 4 rpm, 2 = 5 rpm, 3 = 6 rpm
D = Direction	1 = Pro-spin, 2 = Anti-spin

Table 48. Mean Performance Time for Tangential Walking

30 ft flat 6.308[a]	30 ft curved 5.779	50 ft flat 4.807	50 ft curved 5.051	70 ft flat 7.117
4 rpm 6.235	5 rpm 5.808	6 rpm 5.396		
Pro-spin 5.663	Anti-spin 5.962			

[a]Time in seconds for one traversal (unweighted)

Table 49. Newman-Kuels Analysis of Tangential Walking Performance

CONDITIONS

	C4	C2	C1	C5
C3	NS	**	**	**
C4	- - - -	*	**	**
C2		- - - -	NS	**
C1			- - - -	**

CONDITION/ROTATIONAL RATE

	C1V1	C2V1	C1V2	C5V3	C5V2	C5V3
C3V3	**	**	**	**	**	**
C4V3	*	*	**	**	**	**
C3V2	NS	NS	**	**	**	**
C4V2	NS	NS	*	**	**	**
C2V3	NS	NS	NS	*	*	**
C4V1	NS	NS	NS	NS	NS	**
C3V1	NS	NS	NS	NS	NS	**
C2V2	NS	NS	NS	NS	NS	**
C1V3	NS	NS	NS	NS	NS	**

* Significant at the 0.5 Level
** Significant at the 0.1 Level
NS Not Significant

Key - V1 = 4 rpm, V2 = 5 rpm, V3 = 6 rpm
C1 = 30 ft (9 m), flat floor; C2 = 30 ft (9 m), curved floor;
C3 = 50 ft (15 m), flat floor; C4 = 50 ft (15 m), curved floor;
C5 = 70 ft (21 m), flat floor.

Evaluation of rotational rates revealed that 4 rpm was significantly slower than performance at the 5 and 6 rpm rates. This factor is related to the poorer body control in starting and stopping at the 30-ft (9 m) radius, which was significantly poorer than the other two radii. The analysis of combinations of floor conditions and rotational rate (Table 46) verifies the last observation, as well as showing that the 50-ft (15 m) was the best radius for normal walking, regardless of floor configuration, with the fastest rate being at 6 rpm. This combination was significant at the 0.01 level in contrast to all other conditions and rates. Likewise, the combination of 6 rpm and 50 ft (15 m) curved floors was significantly better than all other combinations at the 0.05 level.

Cargo Transport

These evaluations were performed in conjunction with, and under the same conditions, as the walking test. The cargo packages used for this test were independently supported from the overhead trolley system. Each cargo package has external handles for carrying. The task consisted of one practice and two experimental trials in each direction, with each of two packages, weighing 32 and 96 pounds (14.5 and 43.5 kg). A trial started at one end of the room with the test subject walking to the opposite end, carrying the package. The test subjects were instructed to walk at a comfortable pace, maintaining balance and bodily control. The test subject was instructed to come to a stop before contacting the opposite wall. The heavy package was not used at the 70-foot (21 m) position during the 6 rpm rotational rate due to difficulty of handling the package by the assisting test subject. The task was timed and selected traverses were filmed for subsequent analysis. Subjective comments were obtained through questionnaires and debriefings.

Cargo Transport Results

The impact of carrying either a 32- or 96-pound (14.5 and 43.5 kg) cargo mass on walking rate is presented in Table 50. These data, including the results of the previous study (Reference 8) for the light mass transport are plotted against the g level in Figure 15. It will be noted by comparison of Table 46 and 50 that the locomotion rates, while transporting the cargo, are increased in comparison to simple walking at the lower g levels, but decreased slightly at levels above approximately 0.5 g. The results of faster walking, with cargo, at the lower g levels are probably related to increased traction, and the use of the mass by the test subject to shift the center of gravity, and alter his total inertia, by pushing the package quickly forward to start walking and drawing it backward to assist in stopping. The impact of

Table 50. Variations in Walking Rate While Carrying Cargo as a Function of Rotational Rate, Radius, Orientation, and Floor Configuration

Orientation	4 rpm		5 rpm		6 rpm	
	Pro-	Anti-	Pro-	Anti-	Pro-	Anti-
Condition	32 lb (14.5 kg)					
flat 30 ft (9 m)	2.2(.67)[a]	1.9(.58)	2.1(.64)	1.9(.58)	2.2(167)	2.0(.61)
curved 30 ft (9 m)	2.4(.73)	2.1(.64)	2.4(.73)	2.4(.73)	2.4(.73)	2.5(.76)
flat 50 ft (15 m)	2.5(.76)	2.6(.76)	3.1(.94)	2.8(.85)	3.1(.94)	3.1(.94)
curved 50 ft (15 m)	2.3(.70)	2.4(.73)	2.8(.82)	2.8(.82)	3.0(.91)	3.0(.91)
flat[b] 70 ft (21 m)	2.6(.79)	2.8(.85)	4.1(.94)	3.1(.94)	3.1(.94)	2.7(.82)
	96 lb (42.5 kg)					
flat 30 ft (9 m)	2.2(.67)	1.8(.55)	2.0(.61)	1.8(.55)	2.1(.63)	1.9(.58)
curved 30 ft (9 m)	2.2(.67)	1.9(.58)	2.3(.70)	2.2(.67)	2.5(.76)	2.4(.73)
flat 50 ft (15 m)	2.6(.79)	2.4(.73)	2.8(.85)	2.7(.82)	3.0(.91)	2.7(.82)
curved 50 ft (15 m)	2.3(.70)	2.4(.73)	2.7(.82)	2.7(.82)	3.0(.91)	2.8(.82)
flat[b] 70 ft (21 m)	2.5(.76)	2.6(.76)	2.8(.85)	3.1(.94)	-	-

[a] Values are ft/s (m/s)
[b] Values weighted with 4 and 5 rpm performance data from previous study (Ref 8) to reduce learning error in the present study.

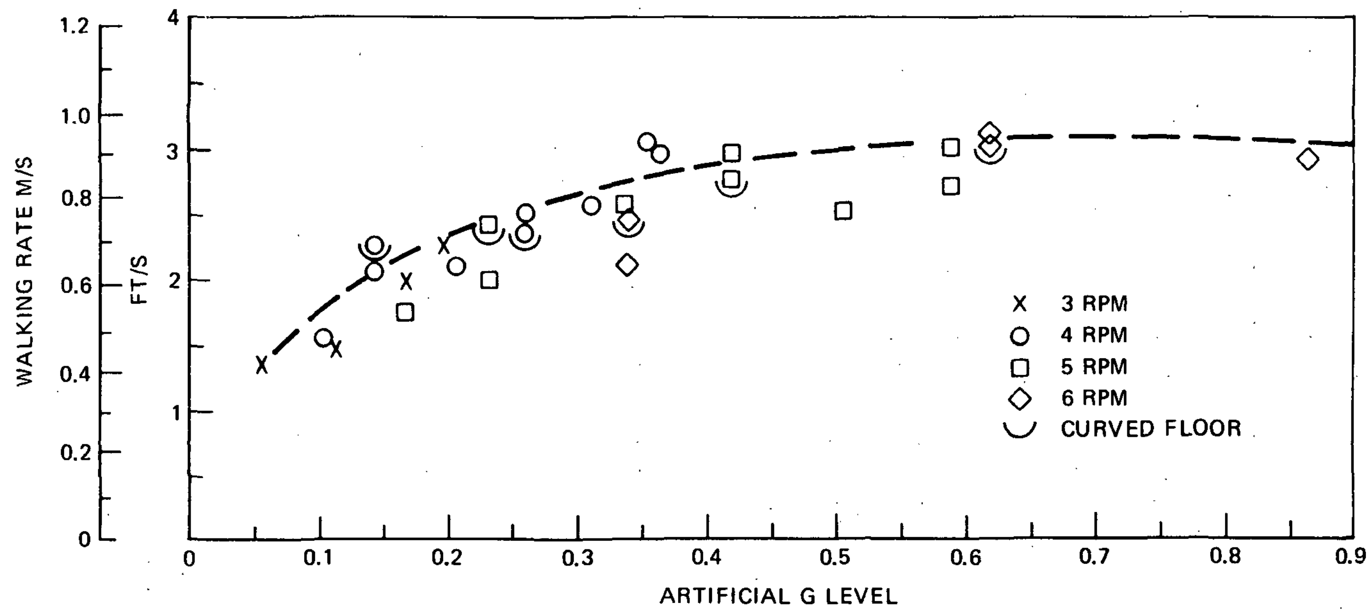

Figure 15. Variations in Walking Rate While Carrying 32-Pound (14.5 kg) Mass Relative to Rotational Rate, Floor Configuration, and Artificial g Level

the increasing g force, while walking in the pro-spin direction, is apparent at radii up to 40 feet (12 m) (see Figure 15), but mixed effects were observed at the longer radii. The curved floors were an advantage at the 30-foot (9 m) radius with both the light and heavy cargo masses, especially from the subjective viewpoint, and were found to be numerically faster, though not statistically significant (Table 51 and 52). The performance at the 70-foot (21 m) position was not analyzed statistically due to a number of incompleted tasks caused by malaise and the very marked learning effect. On the basis of the weighted data (Table 50), the performance probably would have been quite comparable to that obtained at 50 ft (15 m). There was no difference in performance on flat versus curved floors at the 50-ft (15 m) position in the case of either the light or heavy packages. However, all performance at 50 ft (15 m) was superior to that at the 30-ft (9 m) radius ($P \leq 0.01$). The performance at 4 rpm was found to be significantly slower than at either 5 or 6 rpm ($P \leq 0.01$), and performance in the pro spin direction was faster than that in the anti-spin. This is presumed to be due to the increased traction provided by the Coriolis forces generated during the tangential locomotion.

Certain individuals elected to run or leap during both the simple walking and the cargo transport task. The mean rates, while more varied than the more controlled efforts, were quite similar for both walking and cargo transport. The mean locomotion rates were about 3.3 ft/s (1 m/s) between 0.1 and 0.4 g, and increased to 4.3 to 5 ft/s (1.3 to 1.5 m/s) between 0.5 and 0.8 g. No adverse vestibular stimuli were observed or reported by these individuals.

Cargo Pickup

A task was designed in association with the walking and cargo transfer tasks which would test the test subjects ability to maintain bodily control, start, stop, stoop, and lift either of the two suspended cargo packages. These evaluations were conducted at all three rotational rates and at the three radii selected for the walking room. The technique involved the suspending of the 32-pound (14.5 kg) or the 96-pound (42.5 kg) packages, sequentially, and setting them on the walking surface at the feet of the suspended test subject. The test subject would then stoop down, pick up the package, walk to the center of the room, set the package down, stand up, stoop down and pick up the package, walk to the far end of the room, set the package down, and then stand up. The task was timed from the point in which the individual made the first movement to pick up the package until he had assumed the upright position at the opposite end of the 20-ft (6 m) room. The task was repeated three times in each direction, with each package.

Table 51. Effects of Rotational Rate, Orientation, Radius, and Floor Configuration on Cargo Transport Performance

rpm		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
4	Pro-	5.88	5.78	5.48	6.00	5.31	4.99	5.56	5.55	8.14	8.55
	Anti-	6.93	7.33	6.35	6.70	5.19	5.50	5.60	5.51	7.72	7.94
5	Pro-	6.15	6.50	5.43	5.61	4.23	4.60	4.83	4.85	6.96	7.59
	Anti	6.70	7.29	5.46	5.94	4.59	4.74	4.70	4.94	6.71	6.86
6	Pro-	5.70	6.11	5.42	5.34	4.16	4.39	4.39	4.40	6.66	—
	Anti-	6.35	7.06	5.29	5.5	4.23	4.76	4.44	4.70	9.36	—
	Means	6.28	6.68	5.57	5.84	4.61	4.83	4.92	4.99	7.59c	7.74c
		4 rpm- 5.85		5 rpm- 5.41		6 rpm- 5.14					
		Pro-Spin- 5.27		Anti-Spin- 5.65							

Values are mean time in seconds for one traversal
These values were not utilized in means or statistical analyses due to the magnitude of the learning error.

Key: C1 = 30 ft (9m), flat floor, light package; C2 = heavy package; C3 = 30 ft (9m), curved floor light package; C4 = heavy package; C5 = 50 ft (15m), flat floor, light package; C6 = heavy package; C7 = 50 ft (15m), curved floor, light package; C8 = heavy package; C9 = 70 ft (21m) flat floor, light package; C10 = heavy package

Table 52. Analysis of Variance of Cargo Transport Performance

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
C	182.42	7	26.06	15.89	0.001
V	31.96	2	15.98	9.74	0.001
D	13.43	1	13.43	8.18	0.001
CV	12.58	14	0.89	0.54	0.005
CD	11.35	7	1.62	0.98	----
VD	1.78	2	0.89	0.54	----
CVD	3.86	14	0.27	0.16	----
MS w/in cell	532.75	324	1.64		

Key: Factors

C - Conditions
- 1 = 30 ft, flat floor, light package;
- 2 = 30 ft, flat floor, heavy package;
- 3 = 30 ft, curve floor, light package;
- 4 = 30 ft, curved floor, heavy package;
- 5 = 50 ft, flat floor, light package;
- 6 = 50 ft, flat floor, heavy package;
- 7 = 50 ft, curved floor, light package;
- 8 = 50 ft, curved floor, heavy package;
- 9 = 70 ft, flat floor, light package;
- 10 = 70 ft, flat floor, heavy package

V - Rotation Rates
- 1 = 4 rpm
- 2 = 5 rpm
- 3 = 6 rpm

D - Direction of Travel
- 1 = Pro-Spin
- 2 = Anti-Spin

(Note: C9 and C10 were not utilized in the statistical analyses due to magnitude of learning error)

Table 53. Newman-Kuels Analysis of Cargo Transport Performance

Conditions	C3	C4	C1	C2
C5	**	**	**	**
C6	**	**	**	**
C7	*	**	**	**
C8	*	**	**	**
C3	--	NS	*	**
C4		--	NS	**

Rotational Rate	5 rpm	4 rpm
6 rpm	NS	**
5 rpm	--	**

* Significant at the 0.05 level
** Significant at the 0.01 level
[a] See Table 51 for Key

Cargo Pickup Results

The data from this test are presented in Tables 54 through 55. The data for the 70-ft (21 m) position were not utilized in the analyses of variance because at the large error produced by initial test subject caution and learning effects. Further, as noted under the section on cargo transfer, the heavy package was not used at the 70-ft (21 m) position at the 6 rpm rate due to potential hazards in handling the mass in the increased resultant g field (~1.4g). The mean values for performance revealed that the 6 rpm cargo pickup rate is faster than 5 rpm rate which is faster than the 4 rpm rate. However, this difference was not statistically significant. The performance time in the pro-spin direction is significantly faster than the anti-spin (P .01), presumably due to the increased traction produced by the positive longitudinal Coriolis forces.

Table 54. Effects of Rotational Rate, Floor Configuration, and Cargo Weight on Cargo Pickup During Tangential Locomotion

	C1[a]	C2	C3	C4	C5	C6	C7	C8	C9[c]	C10[c]
4 rpm Anti-Pro	11.96[b]	11.98	12.18	12.45	11.16	10.99	12.38	12.16	18.55	17.98
	15.46	15.34	14.43	14.19	11.63	11.49	12.46	12.53	17.70	17.96
5 rpm Anti-Pro	13.25	13.54	12.28	12.03	9.86	10.18	10.80	10.86	15.42	16.10
	15.41	14.98	13.63	13.60	10.03	10.53	10.89	11.33	14.41	15.17
6 rpm Anti-Pro	12.2	13.38	12.70	12.61	9.55	10.68	10.87	11.34	16.46	
	14.61	14.65	13.43	13.64	9.64	9.01	11.44	11.97	15.90	
Mean C	13.82	13.98	13.11	13.08	10.31	10.48	11.47	11.69	16.40[c]	16.80[c]
Mean	4 rpm 12.67		5 rpm 12.07		6 rpm 11.98					
Mean	Pro-Spin 11.72		Anti-spin 12.76		Light 12.18		Heavy 12.30			

[a]See Table 55 for Key

[b]Mean time in seconds to complete one sequence

[c]These values were not used in statistical analyses due to magnitude of learning error.

Table 55. Analysis of Variance - Cargo Pickup Performance

Source of Variation	Sums of Squares	Degrees of Freedom	Mean Squares	F-Ratio	Probability
C	679.51	7	97.07	9.33	0.001
V	34.89	2	17.44	1.67	0.20
D	195.08	1	195.08	18.75	0.001
CV	54.97	14	3.92	0.37	----
CD	84.69	7	12.09	1.16	----
VD	12.89	2	6.44	0.61	----
CVD	19.03	14	1.35	0.12	----
MS within cells	3371.44	324	10.4		

Key: Factors

C - Conditions
1 = 30 ft (9m), flat floor, light package;
2 = 30 ft (9m), flat floor, heavy package;
3 = 30 ft (9m), curved floor, light package;
4 = 30 ft (9m), curved floor, heavy package;
5 = 50 ft (15m), flat floor, light package;
6 = 50 ft (15m), flat floor, heavy package;
7 = 70 ft (15m), curved floor, light package;
8 = 50 ft (15m), curved floor, heavy package;
9 = 70 ft (21m), flat floor, light package;
10 = 70 ft (21m), flat floor, heavy package

V - Rotation Rate 1 = 4 rpm, 2= 5 rpm, 3= 6 rpm

D - Direction 1 = Pro-Spin, 2= Anti-Spin

Table 56. Newman-Kuels Analysis of Cargo Pickup Performance

	C_4	C_3	C_1	C_2
C_5[a]	**	**	**	**
C_6	**	**	**	**
C_7	NS	NS	**	**
C_8	NS	NS	**	**

a See Table 54 for Key
** Significant at the 0.01 Level
NS Not Significant

Statistical analyses of the test conditions, with respect to floors and package weights, reveals that there were no differences for the floor configurations, although the curved floor was preferred subjectively at the 30-ft (9 m) position. The best performance time ($P \leq .01$) was accomplished on the flat floor at 50 ft (15 m), although it was not statistically better than the curved floor. The rate of either 5 or 6 rpm at 50 ft (15 m) provides the best combination ($P \leq .01$), with 6 rpm being numerically the best. There was an insignificant difference in time of performance with the light package in comparison to the heavy package, under the conditions of this study.

Cargo Handling

The cargo handling evaluations were performed in an attempt to evaluate the combined effects of floor configuration, operator orientation, handling provisions, and the net effects of the various forces acting on the packages, as these related to the overall ability of the test subjects to accomplish the specified handling functions. The simulated 8-chambered stowage bins were located at the pro-spin and anti-spin ends of the walking room. The various simulated cargo packages, size, mass, and handle configurations are described in Table 1. Each stowage bin was configured initially with three 4 in. by 12 in. by 12 in. packages located in the left-hand uppermost chamber (as viewed by the subjects). The compartment located immediately below this one contained four 6 in. by 6 in. by 12 in. packages, and the right hand uppermost chamber contained a single 12 in. by 12 in. by 12 in. package. All packages were initially oriented with a single handle exposed to the test subjects. The heavy and light packages were sequentially located in either the pro- or anti-spin bins, respectively. The first handling sequence required the test subject to relocate the three 6 in. by 6 in. by 12 in. packages to the extreme lower left-hand chamber, the four 4 in. by 4 in. by 12 in. packages to the second-from-the-bottom right-hand chamber and the 12 in. by 12 in. by 12 in. to the extreme lower right-hand chamber. The second sequence required repositioning of these packages to their original positions, maintaining the single handle in the out orientation. The third sequence involved essentially the same operations as the first but, in addition, required reorientation, by turning of the packages such that two handles on the opposite end of the packages were exposed to the subject. The fourth sequence required return of the packages to their initial locations without turning, in order to retain two handles exposed to the test subject rather than one. The fifth sequence necessitated turning of the packages and transfer to the lower chamber with the single handles out, as in the second sequence. The sixth and final sequence required restoration of the packages to their initial locations and handle orientations. This same series of sequences was then repeated at the anti-spin end of the walking room with packages having the alternate mass values. Each sequence was timed individually, with subjective impressions solicited relative to the performance of these tasks.

Cargo Handling Performance Results

The mean times to transfer the light and heavy packages with respect to radius, rotational rate, and package manipulation are presented in Table 57. There was no difference, objectively or subjectively, relative to the pro- or anti-spin direction. However, strong preference for the curved floor configuration over the flat floor was expressed for both the 30- and 50-ft (9 and 15 m) radii. The numerical data indicated that performance time was increased on the curved floors, particularly at the 30-ft position and at 4 rpm. It is quite probable that performance time was not a good measure for this test, inasmuch as the attempt to develop speed resulted in canting and binding of the cargo packages, resulting in slower performance. Also, it should be noted that the apparently slower time of the 70-ft (21 m) radius was related to learning error, because this radius was used for the first portion of the program and was not subsequently re-evaluated. The best performance was obtained at the 50-ft radius, as was found for and discussed in the sections on walking and cargo transport.

The strong subjective preference for the curved floors was reported to be related to the fact that both the test subject and the face of the stowage bin were aligned with the radial vector. This configuration made it possible to remove, manipulate, and reinsert the packages without moving either the body or feet excessively. The requirement for bodily movement during cargo manipulation was found to be particularly noticeable at the 30-ft (9 m) radius. It was felt that this factor decreased body stability. The better performance on the flat floors may have been related to greater care on the part of the test subject while removing and reinserting to package due to perturbations to balance when the packages would bind.

Table 57. Cargo Handling Performance

Radius	Floor	Task	4 rpm Light	4 rpm Heavy	5 rpm Light	5 rpm Heavy	6 rpm Light	6 rpm Heavy	Total
30 ft (9m)	Flat	Simple	17.5	18.7	19.0	21.4	17.6	20.9	19.2
		Turn	19.7	22.8	21.1	26.3	19.7	25.1	22.3
	Curve	Simple	19.2	24.9	18.8	23.6	18.9	23.6	21.5
		Turn	21.6	29.2	22.5	25.2	22.5	25.8	24.5
50 ft (15m)	Flat	Simple	17.8	19.0	16.0	17.8	16.6	18.8	17.7
		Turn	19.8	23.7	17.9	20.2	18.3	20.7	20.1
	Curve	Simple	19.8	21.3	18.1	20.5	17.2	18.5	19.2
		Turn	22.0	24.9	20.5	22.7	18.5	20.8	21.6
70 ft (21m)	Flat	Simple	23.0	32.9	22.6	27.1	21.9	25.7	25.5
		Turn	27.7	37.7	26.1	34.0	27.0	29.1	30.3
Totals	Flat	Simple	19.4	23.5	19.2	22.1	18.7	21.8	20.8
		Turn	22.4	28.1	21.7	26.8	21.7	25.0	24.3
	Curve	Simple	19.5	23.1	18.5	22.1	18.1	21.1	20.4
		Turn	21.8	27.1	21.5	24.0	20.5	23.3	23.0

See Table 1 for package weights
Values are time in seconds to transfer packages from top of cargo bin to bottom, or vice versa.

It was observed that the doubling of the weight of the individuals packages resulted in decrement in performance time of approximately 15 percent, regardless of radius, floor configuration, or rotational rate. Also, the requirement to remove, turn, and reinsert the packages produced a decrement in performance time of 10 to 18 percent. These two factors were found to be consistent in all test subjects. Post-test discussions with test subjects disclosed that, subjectively, the time and energy required to complete the defined handling tasks was approximately the same for both the pro- and anti-spin orientations. This observation however, could not be quantitatively verified due to the excessive variations in handling rates. Attempts for speed would result in cargo binding, and thus, produced erratic results throughout the test series.

Neither the Coriolis forces nor the cross-coupled angular accelerations were of sufficient magnitude to adversely affect the handling efficiency of packages with the dimensions and mass of those used in this study (see Table 1). Also, the gravity gradient between the top and lower bins, which was approximately 19 percent at the 30-foot radius, did not produce any adverse comments nor affect performance. The test subjects automatically reverted to the use of a single handle, placing the second hand at approximately the center of mass of the packages, during manipulation of both the double- and single-handled package configurations. This technique of handling allowed more precise control and facilitated insertion of the packages into the chambers, while reducing the tendency of the packages to torque about their center of mass, due to the cross-coupled angular accelerations.

III. DISCUSSION

The results of human response to the performance of specific tasks, as evaluated on the NR/SD RTF, at angular rates to 6 rpm and radii to 80 ft (24 m) will be discussed herein. It is recognized that the various responses were impacted by the complexity of the force vectors produced by rotation within the earth's one g force field. Further, many of the responses would be significantly modified by more completely adapting the individual test subjects to the stimuli of the rotational environment (References 20 and 21).

However, specific efforts have been expended to evaluate the simulated artificial g vector by means of couches and sling systems. Further, the Coriolis forces and cross-coupled angular accelerations will be similar in both magnitude and direction in the rotating space vehicle. The potentially greater vestibular-proprioceptor stimulation of the earth-bound simulation, therefore, may represent a "worst case condition." The human responses and corrective measures established in this environment should be more than adequate in the less complex force field of the rotating space base. While the impact of various degrees of adaptation should be pursued prior to establishment of final crew procedures and mission profiles, the problems associated with early residence in a rotating vehicle were considered to be of paramount importance, and served as the basis of the experimental design for this program. The test subject population used in these evaluations represented a good cross-section of individual responses to the rotational stimuli, ranging from highly susceptible to highly resistant with respect to motion sickness. It is of academic interest to note that the individual susceptibility to the rotational environment could not be correlated with the individual's overall health, physical fitness, or sensitivity to vestibular tests such as caloric stimulation. There was a suggestion of a relationship of a negative response to tilt with an individual's response to the stimulation of rotation, i.e. the greater the narrowing of pulse pressure during tilt, the greater the susceptibility to motion sickness. This possibility should be investigated more completely, with a greater test subject population.

ROTATIONAL RATES

Increases in the rotational rate, up to 6 rpm, generally resulted in a negative effect on the rate of accommodation, postural equilibrium, psychomotor performance, and resistance to the onset of malaise. These negative influences were manifest at 5 rpm, and at 6 rpm resulted in marked restriction on motion and overall performance, especially during the earlier experiences. This negative aspect of the high rotation rates can be compensated somewhat by careful test subject selection and indoctrination. It is most probable that continuous exposure of individuals to graded levels of stimulus for 48 to 72 hours would result in adaptation and tolerance of the relatively high levels of vestibular stimulation, but the individuals were not able to reach a level of complete comfort at 6 rpm following more than 20 periods of intermittent exposures. However, at rotational rates of 5 rpm or less, this group of individuals reported growing comfort in the rotational environment and demonstrated a freedom of movement, and level of performance, comparable to that observed in a nonrotating environment. The exposure of a large number of naive individuals to rotational rates of 3 to 5 rpm, during indoctrination and public relations activities, indicates that more than 95 percent of the population is able to tolerate rotation at 4 rpm, provided adequate information is provided to reduce the effects of anxiety caused by the various stimuli.

ORIENTATION

The overall evaluations of orientation on comfort and performance are incomplete, requiring additional investigation. However, it has been found that orientation in a pure tangential or axial direction is most comfortable and favors the performance of both fine and gross motor tasks. It was found that performance was subjectively, and in some cases, objectively, more efficient and comfortable while facing the anti-spin and axial directions than that while facing pro-spin. While it must be noted that adequate adaptation reduces the overall subjective response to the various forces developed in the rotational environment, it appears desirable to arrange controls, displays, and work areas in such a way as to minimize the requirement for excessive head and limb movements (see References 10 and 18). However, the test subjects used in the prior study for the continuous seven-day evaluation (Reference 8) did not demonstrate or report any conscious effort in the restraint of head or limb motions following the first 24 to 36 hours of exposure.

RADII

The comparison of similar psychomotor tasks at different radii did not produce measurable differences in performance. However, the subjective response was definite that the stimuli at the longer radii were more severe than those at 50 ft (15 m) or less. This was especially true at the 5 and 6 rpm rotational rates, with the greatest adverse stimuli encountered in the crew module, at a mean radius of 75 ft (23 m). It is recognized that the magnitude of the Coriolis forces and cross-coupled angular accelerations are the same at all radii at constant velocities. However, the centripetal force, the induced vector, and consequently the lean angle are different at the short and long radii. However, the lean angle in the crew module is minimum due to the fact that the floor is canted to provide a surface normal to the induced g vector, and yet, the overall stimulus was more provocative. It was observed and reported frequently, that a feeling of malaise could be reduced or eliminated by moving to a shorter radius, usually to approximately 30 to 40 ft (9 to 12 m). No explanation can be given for this response. This phenomenon was not reported for the 3 or 4 rpm rotational rates.

CORIOLIS FORCES/CROSS-COUPLED ANGULAR ACCELERATIONS

The Coriolis forces experienced in the course of these evaluations presented no difficulties relative to crew comfort or performance. Accommodation was quickly developed for locomotion, postural equilibrium trials, limb movement tasks, and cargo handling. During tangential locomotion, changes in local g levels caused by Coriolis forces, did produce slight but unimportant performance changes. During radial locomotion in the elevator, no discomfort was experienced, nor during cross-over of the nonrotating hub. These forces somewhat complicated the ladder task, due to interactions with rotation rates, changing radii (g levels), and direction of travel; but after repeated exposures, performance was completely satisfactory. Accommodation to these forces during radial transfer will require a degree of test subject familiarization, as well as provisions for hand holds or other stability devices to insure maintenance of body control. This would be particularly true for elevators, hallways, tunnels, or areas where cargo might be carried in the rotating space vehicle.

Cross-coupled angular accelerations, developed by motion within the environment, produced obvious impacts, both on the limbs of the crew and the cargo, and also through complex vestibular stimulations. Sufficient handholds or restraints, as well as experience in moving items in the environment proved to be satisfactory in reducing the overall effects on the test subjects. In some cases, the test subjects actually were able to utilize these forces to their advantage in cargo manipulation and locomotion. Prior to developing a degree of tolerance to the forces, the subjects learned quickly to avoid motions which produced excessive vestibular stimulation, created by cross-coupled angular accelerations in such activities as bending over, or other actions requiring motion in more than one plane, or else to perform them at a comfortable rate. The provocativeness of the stimulations received were a function of the rotation rates. The higher rotation rates, 5 rpm or greater, resulted in increasing loss of performance speed, flexibility, and freedom of movement, due to the avoidance of the excessively provocative stimulation.

PHARMACEUTICAL EVALUATIONS

The use of selected antimotion sickness pharmaceuticals produced little in the way of conclusive results in these limited evaluations. It is recognized that this result was related to the limited number of tests and test subjects. Research efforts in other laboratories have conclusively demonstrated the positive effects of certain of the formulations in modifying the response of individuals to the stimuli produced in the rotational environment (References 13, 24, 25). The three compounds and placebo used were provided by Dr. Graybiel, and were selected on the basis of their predicted effectivity or lack thereof. With respect to overall sense of well being, the various compounds reacted as expected, with the exception that the Phenergan/Ephedrine combination appeared to be superior to the Scopolamine/Dexedrine combination, but not to a great extent. Also, the Dramamine provided better protection than had been expected on the basis of the results reported earlier (Reference 24). The relatively high number of individuals who reported side effects with the Scopolanime/ Dexedrine combination was not expected. These reports, while randomized, may have been the result of excessive introspection. It is of interest to note that the overt symptomology generally correlated with subjective feelings and also, with the stress inventory, as determined by analysis of mood factors. The results of the reading test suggested a pharmaceutical interaction on vocabulary and comprehension which may not be related to rotation. The data were too limited in numbers to permit statistical handling, but suggested a negative reaction with the stronger pharmaceutical combinations, lowering the resultant scores of the mental tests. In addition, during the pharmaceutical evalution, the test subjects complained of excessive drowsiness (or fatigue) following a test session on the RTF, particularly with the Phenergan/Ephedrine combination. The results of performance with the various psychomotor test devices were generally not significantly different from the normal test program.

While the pharmaceuticals used in this study did offer some protection from motion sickness, this protection was not of sufficient magnitude in this program to encourage the use on a regular basis. In addition, while the specific compounds may delay the onset of motion sickness, or reduce its severity, they will not prevent the occurrence of symptoms on an absolute basis (Reference 13).

POSTURAL EQUILIBRIUM EVALUATIONS

The ataxia tests of postural equilibrium performed in this phase of the rotational test program were extensions of earlier findings of the first phase and previous studies done in slow rotation rooms (References 8 and 17). The current tests were intended to explore the rate of accommodation to the rotating environment and recovery or readaptation to nonrotation following a series of relatively short exposures. Rotational adaptation of postural equilibrium was explored during continuous 4 rpm rotation over a seven-day period, for both eyes open and eyes closed performance in the earlier program (Reference 8). The improvement compared to baseline levels was relatively complete for eyes open by the end of three days. For eyes closed, it approached but never reached baseline levels by the end of the seven days. In the current tests, eyes open performance reached baseline for four and five rpm and approached it for 6 rpm. Eyes closed performance never significantly improved at any rotation rate during the short exposures of this program. From these evaluation periods, it is possible to conclude that eyes open performance is superior, and visual reference is critical for adequate postural equilibrium. Eyes closed performance does improve moderately following adaptation to 4 rpm, but at the higher rates, this may not be the case. It would appear, on the basis of the current study, that eyes closed performance cannot be expected to improve sufficiently at rates of 6 rpm or greater to make working unrestrained, in the dark, a safe procedure.

The importance of vision for the maintenance of postural equilibrium and positional stability may be inferred on the basis of visual illusions in response to the rotational stimuli (References 22 and 23). Based on the test experience, the loss of lighting (visual cues) could result in danger to the crew due to confusion relative to body position and orientation, as well as an increase in visual-postural illusions. It is possible that the less complex forces (i.e. lack of earth g) in the rotating space vehicle will reduce the severity of this problem, but that is a factor of magnitude, not of occurrence. This concept is based upon the fact that both centripetal and Coriolis forces will be present, but also cross-coupled angular accelerations. The magnitude of this problem requires further evaluation, but it is safe to say that both visual and tactile cues should be provided to assist in the establishment of adequate positional stability and body control.

The evaluations of the time sequence and attendant factors related to postrotation recovery revealed that the rate of recovery, following short-term exposures (<8 hrs) to rotational rates of 3 to 6 rpm, is relatively independent of the rotation rate. Further, recovery following short-term rotational exposures is essentially complete within an hour and a half, while for longer duration exposures (>3 days) recovery will require up to 4 hours, with the majority of symptoms gone with 24 hours. Regardless of the rate or duration (up to 7 days at 4 rpm), most of the recovery takes place within the first two hours. Body movements, such as walking (or performing the ataxia test battery) aid significantly in recovery rates.

PSYCHOMOTOR/COGNITIVE FUNCTIONS

The results associated with the various psychomotor/cognitive tests did not yield consistent or conclusive results in all cases. However, sufficient trends were evident to draw certain conclusions. In general, any aspect of the environment which created stress, provocative stimulation to the vestibular system, or situations that created motion sickness symptoms, did influence psychomotor task performance. Rotation rates of 6 rpm, did, with some consistency, negatively influence performance. There was some evidence of a performance decrement at 5 rpm. In general, the trend increased with rotational rate, with the 6 rpm level being generally significant, and rotation, in general, causing a performance loss in these intermittent exposures. Where the task components were primarily mental, the environmental influence must be attributable to the stress of rotationally induced stimulations. This was most evident where the stimulations were highest, such as following programmed head motions, or where the rotational parameters were the most provocative, such as 6 rpm at 80 ft (24 m). Experimental testing of longer duration exposures indicates that an adaptation process does occur, and is reflected in the return of mental performance to a point near the prerotational performance level.

The cognitive behavior response to the stimuli of the rotational environment is evident in loss of short-term memory and problem solving capability, as well as observable mood attitude changes. These results were observed both through objective measurements and observations of behavior, in addition to subjective comments. Mild speech difficulties, difficulty in remembering assignments, inability to solve unexpected problems, depressed mood levels, and a marked lack of enthusiasm characterized this response during the earlier phases of the rotational experience. In general, however, the losses of capability were never of sufficient severity to suggest that humans could not operate effectively in the rotational environment. This eventuality only would pertain to those highly susceptible individuals who might develop motion sickness to the point of severe nausea. Such motion sickness was very infrequent in this program, even at 6 rpm.

Langley Complex Coordinator

The LCC was utilized to evaluate hand, foot, and eye coordination, as well as some degree of mental function through the complex mix mode. Specifically, the factors influencing performance include rotation rates, orientations, head motions, fatigue/stress, pharmaceuticals, and task complexity. This test device has, in the past, been successfully used by personnel at NASA/Langley Research Center in evaluating other stressful situations, such as hypoxia and alcohol influences. The results obtained in the rotating environment, in general, indicate that the measure of human performance utilizing these devices is comparable to that obtained during nonrotation. Evidence from the results of this program indicates that the higher rotation rates (>5 rpm) may produce negative effects, with respect to psychomotor performance on this device. In addition, movement between stations appears to have influenced performance negatively. No significant findings have been made relative to test subject orientations, nor any effect from head motions. One pharmaceutical combination (Scopolamine/Dexedrine) did produce a significant increase in errors committed, during testing at 6 rpm. However, the overall performance on the LCC during rotation remained comparable to baseline nonrotation performance. This task does not involve extensive arm motions, but rather, required visual fixation, with no head movement. These factors tend to eliminate any detrimental stimuli or influence of rotation on the individual.

Decision Response Time Device

The evaluations utilizing the DRT have been used to evaluate several aspects of the rotational environment. These have included test subject orientations, head movements, radii, rotation rates, task difficulty, and the fatigue/stress factors related to movement from one test station to another during rotation. The evaluations related to radii, test subject orientations, and head movements did not produce any significant differences in performance, possibly leading to the conclusion that these factors are of no importance to design or crew operations in the rotational environment. However, these findings do not agree with previous studies by other investigators (Reference 9), nor with the results obtained on the RTF with other psychomotor tests. This conflict in results may be related to the particular test conditions utilized with the DRT. The test subject was oriented in the supine position to eliminate the influence of the earth's g field. It is possible that the "cocoon" support, for the purpose of safety and to permit various couch orientations, may have produced a feeling of security such that the response to the vestibular stimuli was reduced to insignificance. This possibility must be evaluated further in future testing. The possibility of this effect is further substantiated by the fact that no malaise has been experienced at any rotational rate or radius by test subjects confined to the couch system. The test results did indicate a slight decrease in performance with increasing rotational rate in comparison to the baseline. No differences in performance were found for various fatigue/stress effects evaluation (MSP vs. SSP).

Stromberg Dexterity

The results obtained in this study phase confirmed earlier findings related to the influence of orientations and the loss of performance time due to rotation rates (Reference 8). This task, with its large arm and head movement requirement, much faster and larger than would normally be required in the operational situation, does respond to the negative aspects of rotation. It should also be noted that the orientation of the vestibular apparatus is different than would occur in the real artificial gravity environment, but the response should be quite similar due to the magnitude of the various forces. Although the test subjects were able to perform the task reasonably well, it was considered stressful because of the head movements and fatiguing because of the rapid arm movements, resulting in a persistent 8 to 12 percent loss, with respect to performance time.

Memory Span

A test for memory span was developed to obtain a quantative measurement of subjectively reported and observed difficulties associated with short-term memory and cognitive functions. These observations, which have not been found in other reported studies, except during discussions with test personnel, have been persistent during the exposure of individuals to rotational stresses on the RTF. The negative results obtained during the earlier attempt to quantify the memory observations can be explained by inadequacies of the measurement technique (Reference 8). The inadequacies were primarily related to the fact that the memory drum did not provide for the wide range of ability among test subjects. The memory span test used in this study employed a slightly different technique, and was open-ended. The results indicated a trend toward a decrease in mental capability with increasing rotation rates. At 6 rpm performance was significantly poorer than the baseline. The subjective impression of greater difficulty in this area of human performance than has been objectively demonstrated persists, particularly in situations that require unique problem solving. From the experience obtained on the RTF, a strong suggestion of greater loss of cognitive capability, related to the particular level of environmental stress, has been observed. This loss appears to be related to short-term memory, problem solving, speech, and ability to react to changing requirements. While it has not been demonstrated conclusively, it may be conjectured on the basis of the observations during the seven day test, that this response may be reduced in magnitude following adaptation by the test subjects.

Reading Test

The reading test was used with the pharmaceutical evaluations to obtain an index of the influence of rotation on mental capacities. Added to it were some programmed provocative head motions, intended to evaluate both their influence, and the effectiveness of the pharmaceuticals. The findings of this test strongly support a conclusion that provocative head movements can seriously degrade mental capacity. The pharmaceuticals did not over-ride the detrimental effects of the head motion. This finding, relative to head motion, supports other findings. However, it is in conflict with the negative results obtained in other tests in this program, such as the DRT and LCC. No explanation based on orientation and force vectors may be proposed for these differences.

LOCOMOTION AND CARGO TRANSPORT

The capability of man to perform relatively complex tasks in strange and foreign environments has been observed by most investigators of human performance (Reference 26). These same phenomena were demonstrated frequently during the course of the study reported herein. As an example, the effort to complicate the cargo handling task by requiring cargo rotation was converted to an advantage as the test subjects used the cross-coupled angular accelration forces to turn the cargo packages. Another example was seen in the use of the heaviest cargo packages to change the center of gravity and impart inertial motion (or decrease the motion) of the man-mass unit by thrusting the mass from the body or drawing it close during tangential locomotion evaluations. Contrary to the many predictions of difficulty relative to gravity gradients, Coriolis forces, cross-coupled angular accelerations, and bizarre vestibular responses to the forces, it has been found that man adapts quite rapidly to these stimuli. It was feared that the visual stimulus of clouds passing overhead, or shadows moving frequently across the floor and walls would present an excessive stimulus to the test subjects in this study. However, these presented no difficulty, even during early exposures. The test personnel ignored their existence, much in the same way an individual driving an automobile is oblivious to the trees, poles, and other objects passing through his peripheral visual field. However, shadows or light shafts moving across an instrument panel or a book might present an entirely different problem relative to visual stimulation and performance. This factor was demonstrated by the slight glare from the open crew module door falling on the LCC display, which was almost unnoticed by the test monitor, but was distracting to the test subject. The problem was relieved by the use of a simple shield to protect the display surface only. The problem of light shafting in the rotating environment has been investigated by R. F. Haines, et al, of the NASA Ames Research Center (Reference 27).

Radial Locomotion

The test subjects and monitoring personnel made frequent excursions along the full length of the 160-foot (48 m) beam, crossing through the center of rotation at a radius of approximately 20 inches (.5 m) without ill effects. The predicted high stress level that could not be tolerated does not exist (Reference 18). The reason for this probably lies in the fact that the g forces are below the perceptible threshold as the subjects approach the hub area. Individuals evaluated this problem area by running across the hub area at rates in excess of 6 ft/s (1.8 m/s), without vestibular or proprioceptor distress. The stimuli generated during passive transfer along the beam at linear rates of 2, 4, 6, 8 ft/s (.6, 1.2, 1.8, 2.4 m/s) while rotating at various rates to 6 rpm did not result in any adverse responses by the test subjects. One case of grade III malaise occurred in response to the cross-coupled angular accelerations when an individual sat up quickly at the 65-foot (20 m) radius during rotation at 6 rpm. It is noteworthy that the relatively high Coriolis forces at the short radii, during high linear rates, are sufficient to present hazard to the crew members in the weightless environment. While there were no adverse responses to the stimuli, the lack of postural stability produced by substantial Coriolis forces in the presence of diminishing centripetal forces requires the use of restraint systems to prevent an individual from being impelled across the elevator.

The rate of ladder climbing averaged 2.5 ft/s (.76 m/s) and reached as much as 4.1 ft/s (1.2 m/s). This mode of transfer was found to be a completely acceptable means of radial locomotion. While the Coriolis forces produced initial difficulty in body control and foot placement for the test subjects, two or three excursions up and down a ladder were sufficient to produce complete muscular accommodation to these forces, and the subjects became proficient at ladder climbing. Predictions made during the earlier study (Reference 8) that ladders with graduated rung spacing would be more effective than a standard ladder with constant rung spacing were verified in this program. The ladder with spacing of 9 inches (22.9 cm) at the long radii to 18 inches (45.7 cm) at the short radii was found to be superior to the constant 12-inch (30.5 cm) spacing of the ladders utilized in the first program, and first phase of this study. However, the shortest spacing (22.9 cm) of the ladder was found to be somewhat awkward and difficult to use, even at 6 rpm. The ladder having a rung spacing of 12 inches (30.5 cm) to 20 inches (50.8 cm) was found to be superior to all other configurations. Also, it was found that the test subjects preferred to hold the side rails and slide, both ascending and descending during rotation at rates of 5 rpm or less. However, attempts to slide during the 6 rpm rates appeared to be potentially hazardous. From the viewpoint of performance, the higher rotation rates (5 and 6 rpm) produced the best results, presumably due to the requirement to use more rungs and thereby, provide a more stable procedure. However, from the subjective viewpoint, the ease of sliding-climbing at 4 rpm was strongly favored. The test subjects determined that the preferred orientation, if the rate was 5 rpm or less, was to face the pro-spin position, since the Coriolis forces held the body away from the ladder during a sliding descent. However, at the higher rate (6 rpm), the preference was for facing in the anti-spin direction, to take advantage of the Coriolis forces in assisting foot placement during the more hazardous descent phase.

Tangential Locomotion

Tangential locomotion was easily accomplished in both the pro- and anti-spin directions, at levels as low as 0.056 g, i.e., 20 ft (6 m) and 3 rpm (Reference 8), and as high as 0.81 g, i.e., 70 ft (21 m) and 6 rpm. There were no excessively severe responses produced during tangential locomotion, but the complex stimuli encountered when stooping to pick up or set down the cargo packages, were somewhat distressing to the more susceptible individuals, especially at the 70-ft (21 m) radius. However, these stimuli seldom affected the individuals overall performance in the walking room. It was found during the previous evaluations at the 20-ft (6 m) radius on flat floors (Reference 8), that the radial difference between one end of the room and the opposite end made starting and stopping body control quite difficult. This was found to be a slight problem at the 30-ft (9 m)position at the 4 rpm rate (0.14 g) in this study, but was not of great significance, due to the presence of adequate traction for locomotion. The evaluation of the curved floor configuration at the 30-ft (9 m) position did not result in a significant improvement in simple walking performance as measured by time. However, the curved floor configuration was shown to be superior to the flat floors at 30 ft (9 m) while transporting cargo packages across the walking room. Of equal or greater importance, the individuals felt more comfortable on the curved floors at the 30-ft (9 m) radius while performing all tasks. Conversely, there was no objective nor subjective preference for the curved floors over the flat floors at the 50-ft (15 m) radius. The flat floors at this radius tended to result in better performance during both walking and cargo transport. The fastest performance, with and without cargo, was obtained at the 50-ft (15 m) radius at 6 rpm (0.62 g). The rate of locomotion at 70 ft (21 m) at a 5 rpm rate (0.59 g) is comparable to the 50-ft (15 m) position but the greater magnitude of the various stimuli at 6 rpm resulted in less "carefree" motion and, consequently, a significant reduction in performance rate. Tangential locomotion at radii of less than 40-ft (12 m) is slower than that found at the longer radii. For example, a rate of 6 rpm is required at 30-ft (9 m) to permit a normal walking rate (0.34 g) of approximately 3-ft/s (0.9 m/s); and 5 rpm is preferred to 4 rpm at the 50-ft (15 m) position (0.42 vs 0.26 g) for the performance of tasks associated with tangential locomotion. Walking in the pro-spin direction is faster than that obtained while walking anti-spin due to the increased traction provided by the Coriolis forces. This is especially true at the lower g levels and while carrying cargo. It was found that comfort and adequacy of performance required that the test subjects standing lean angle be 60 degrees or greater relative to the floor on the flat floor configuration.

IV. CONCLUSIONS

The objectives of this study were to evaluate the impact of various forces, with the attendant psychophysiological stimuli, on man's abilityto perform operational-type tasks in the rotating environment. The majority of the tasks were designed to permit evaluation within the simulated artificial g vector. These evaluations were calculated to answer various questions relative to design, orientations, training, and crew operational procedures for future long-duration space vehicle/missions of the space base class. It is recognized that there are several inadequacies in the simulation, the greatest being the inability to eliminate the one g vector from the study. However, this factor has been considered to be an advantage in these evaluations, since the response of the vestibular system to the impact at the forces generated in the rotational environment is the most important factor with respect to man's residence in this environment. Further, the Coriolis forces and cross-coupled angular accelerations are similar in magnitude, the vestibular disturbance may be described as a "worst case" in ground-based artifical g simulations. Therefore, those measures which are found to be effective for optimizing crew comfort and performance in this environment will be equal to or better in the less complex environment of the space base. Although it is not possible, through ground-based studies, to determine whether an artificial g or a weightless environment is preferable, relative to the crew operational performance viewpoint, it is possible to evaluate the environment in order to establish proper design and operational protocol for use in rotating space vehicles. The results of the tests used in this program do not suggest that all or a majority of the questions relative to artificial g have been answered; to the contrary, a large number of unknowns have been discovered. Nevertheless, certain findings of significant importance have been made One important finding of this program was that there were no fatigue/stress anomalies present in the experimental protocol. Certainly the test program resulted in fatigue, as any work will, but the interaction between tests related to fatigue were completely negative. The essential conclusions to be drawn from this study may be enumerated as follows:

TANGENTIAL LOCOMOTION AND CARGO HANDLING

1. Curved floors are not required at radii greater than 40 ft (12 m) and provide minimum advantage for tangential locomotion, with or without cargo, at the 30-ft (9 m) radius.

2. Curved floors or tilted storage cabinets would provide a very definite advantage for the stowing and unstowing of equipment from high shelves at radii of 30-ft (9 m).

3. Tangential locomotion activities are more efficient when conducted in the pro-spin direction at forces below approximately 0.3 g due to the additive effects of the Coriolis forces.

4. Tangential locomotion and body control is possible at g levels as low as 0.056, but starting and stopping are difficult because of the low traction, particularly at radii of 20 or 30 ft (6 or 9 m). Locomotion is easy at radii greater than 40 ft (12 m) at rates of 3 rpm or more (0.11 g).

5. On the basis of tangential locomotion, vehicular radii of less than 30 ft (9 m) will require curved floors; at vehicular radii of 40 ft (12 m) or more, flat floors are adequate. These data also indicate that the individual's lean angle should not be less than 60 degrees with respect to the walking surface.

6. Control panels and stowage cabinets should be aligned with the radial g axis at radii less than 50 ft (15 m) if the individual must stand and reach above his head to remove cargo and set it upon the floor.

7. The median tangential locomotion rate is approximately 3 ft/s (0.9 m/s) at force levels above 0.35 g.

RADIAL LOCOMOTION

1. Radial locomotion is possible without excessive physiological distress from the stimuli generated in the rotating environment at angular rates of 6 rpm, and linear rates to 8 ft/s (2.4 m/s).

2. Elevators should be provided with handholds if the programmed linear translation rates are less than 6 ft/s (1.8 m/s), with restraint systems being required at greater translation rates. These requirements are due to the presence of constant lateral Coriolis forces in the presence of diminishing longitudinal centipedal forces.

3. The use of a ladder system is an adequate means of radial transfer of crew members.

4. The use of two ladders is not required for comfortable, effective transfer; i.e., neither the illusions of tilt nor Coriolis forces are so severe that the crew member dislikes the orientation.

5. The effective use of the ladder system includes the process of holding the side rails and "sliding" when the g levels are low enough to permit, during both ascent and descent. For this reason, a ladder permitting the individual to face the pro-spin direction is preferred in order to take advantage of the lateral Coriolis forces in keeping the body away from the ladder during rapid descent during rotation rates to 5 rpm. At rates of 6 rpm or greater, the individual should face the anti-spin direction so that the attendant Coriolis forces would hold him against the ladder as a safety precaution in the presence of relatively high g forces.

6. Ladders having graduated rung spacing, correlated with the local g level, are preferred over a standard ladder with constant rung spacing. The best configuration appears to be approximately 12 in. (30.5 cm) at the 0.9 g level, graduated to 20 in. (50.8 cm) at the 0.1 g level.

7. The mean linear transfer rate for the best ladder systems is approximately 2.5 ft/s (0.75 m/s).

POSTURAL EQUILIBRIUM

1. Postural equilibrium, as determined by adequate locomotion and gross motor performance in the rotational environment, requires an exposure and activity session of approximately 3 hours.

2. Postural equilibrium performance in the rotational environment, as determined by highly disciplined ataxia evaluations, requires approximately two days of continuous exposure at 4 rpm, or approximately 15 to 20 sessions of intermittent exposure to reach non-rotational baseline levels during eyes open tests. The "eyes closed" ataxia performance evaluations are only partially recovered in a period of 7 days continuous exposure at 4 rpm, and less than 10 percent recovered after approximately 20 intermittent rotational exposures. While the force vectors are more complex, and therefore, relative to this factor, more provocative in the earth-bound simulation, lighting as a safety requirement for a rotating space base is an important consideration.

3. Static postural equilibrium, as determined by the ataxia test, is approximately 100 percent restored within one hour, following one-day exposures. The majority of the recovery occurs in less than 30 minutes and is hastened by any body motion.

4. Recovery of static postural equilibrium, following a seven-day continuous exposure, is essentially complete in 4 hours, with all measurable vestiges of instability gone within a period of 24 hours.

COGNITIVE/PSYCHOMOTOR

1. Short-term memory and mental functions are affected by the rotational environment, the degree being roughly related to increasing rotational rate. In addition, there was an effect related to the longer radii at the higher rotational rates which cannot be explained on the basis of present knowledge. The manifestation appears as slurring of speech, inability to modify a learned task response, lack of innovative skills, decrease in reading comprehension skills, and a decrement in expanding digit memory span performance. While the initial severity of this effect was not completely validated by the tests employed, these phenomena seem to significantly decrease or disappear with increasing accommodation/adaptation with time in the rotational environment.

2. The performance of tasks requiring relatively extensive arm and head motions are degraded by the rotational stimuli approximately 8 to 11 percent with increasing rotational rates to 6 rpm. The greatest degradation occurred in these simulations while facing the pro-spin direction.

3. On the basis of performance degradation of tasks requiring extensive in-place body motions evaluated in this program, in order to obtain optimum performance, such tasks on the space base should be arranged so that the crew member faces either axially or in the anti-spin direction.

4. Normal or programmed head motions consistently lower psychomotor performance during all phases of rotational experience due to stimulation of the vestibular apparatus. The magnitude of this effect becomes very small after approximately 48 hours of continuous exposure. In addition, the spontaneous or programmed head motions hasten the process of accommodation/adaptation.

ANTIMOTION SICKNESS PHARMACEUTICALS

1. The rotational stimuli, at the higher rotational rates, produce mood changes during intermittent exposures, which are modified to a significant degree by antimotion sickness pharmaceuticals.

2. The more effective antimotion sickness pharmaceuticals appeared to have a negative effect on short-term memory scores, presumably due to the tranquilizing side effects.

3. The pharmaceuticals were effective in modifying both the severity and frequency of adverse reactions to the rotational environment, but did not prevent the occurrence of malaise, even to the point of emesis. The efficacy of the pharmaceutical combinations used was as follows: Phenergan/Ephedrine was best, followed in order by Scopolamine/Dexedrine, Dramamine, and placebo. The Phenergan/Ephedrine combination resulted in a number of post-rotational fatigue or drowsiness complaints.

TRAINING/ADAPTATION

1. The stimuli of the rotational environment are sensed by all individuals having normal oculo-vestibular-proprioceptor responses. Of approximately 175 individual short-term exposures of naive persons tested up to a 75-foot (23 m) radius, none have been adversely affected at a rate of 3 rpm, approximately 2 percent reached a level of malaise III at 4 rpm, approximately 15 percent reached malaise III at 5 rpm, with 10 percent reaching the pathognomonic state with emesis, and approximately 80 percent reaching malaise III at 6 rpm, with 30 percent of this latter group reaching the pathognomonic state upon initial exposure.

2. Two days of indoctrination, through graded exposures to the rotational environment and positive psychological reinforcement relative to the lack of detrimental effect of the stimuli, reduced the incidence of motion sickness to nil at the 4 and 5 rpm rate and to a level of approximately three percent in approximately 100 exposures to 6 rpm.

3. The exposure of individuals to approximately 12 periods of rotational experience at 3, 4, and 5 rpm, for periods up to 6 hours, resulted in a reduction in the time required to adapt to continuous exposure of 4 rpm by more than 50 percent, and reduced the severity of the response to the stimuli during the initial 8 to 12 hour period in these individuals.

UNSOLVED PROBLEM AREAS

1. One of the principal questions with respect to the artificial g environment is related to what level is required to maintain the overall health of crew members during long duration flights,

including muscular, skeletal, and candiovascular adequacy in order to insure adequate functioning of the individual upon return to the one-g environment of earth.

2. Much additional information is required relative to the selection, indoctrination/training of individuals scheduled to live in an artificial g environment, and the time course of gaining, losing, or maintaining adaptation to the rotational environment prior to space flight.

3. The real problems of the man-machine interfaces, with respect to orientation, configuration, visual fields, crew operational procedures, and workspace analysis must be established to support space base design requirements, including the verification/ modification of various NASA design handbooks which were developed as a part of, or in conjunction with, Phase B Space Base studies.

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